5.0 PLANNING PROCESS

5.1 Introduction

The Plan Formulation section of this document follows the six step planning process defined by the USACE in the Principles and Guidelines (P&G) for water and related land resources adopted by the Water Resources Council (USACE, 2000):

Step 1	Identify problems and opportunities
Step 2	Inventory and forecast conditions
Step 3	Formulate alternative plans
Step 4	Evaluate alternative plans
Step 5	Compare alternative plans
Step 6	Select a plan

5.2 Step 1 - Problems and Opportunities

5.2.1 Problems

As discussed in Section 3.0, Study Purpose and Need, Cartersville Dam presents the following problems:

- The dam is a barrier to upstream passage of native fishes, particularly sturgeon;
- The dam is at risk for failure; and
- The dam is a public safety hazard.

5.2.2 Opportunities

If the Cartersville Dam was made passable to shovelnose sturgeon, it would create the following opportunities:

1. Reinforcing the existing dam will increase the longevity of the structure, thereby providing a more reliable supply of water to irrigators. This would also reduce the cost of maintenance for the ditch company.
2. Allow passage to habitat upstream of Cartersville Dam.
3. Eliminate hydraulic conditions at the dam that create a life-threatening hazard to swimmers and boaters.
4. Allow suitably equipped boats to travel upstream and downstream over the dam.

5.2.3 Planning Objectives

The primary project objectives are:

1. Maintain the ability of the irrigation district to divert water at all water levels
2. Allow upstream passage of native fishes, particularly sturgeon
3. Provide minimal maintenance requirements
4. Increase public safety
5. Maintain recreation opportunities at adjacent city park

5.2.4 Constraints

General types of constraints, as defined by the USACE, include resource constraints and legal and policy constraints. Potential resource constraints include limits on knowledge, expertise, experience, ability, data, information, money and time. The primary constraints for this project are availability of funding and acceptability to the Cartersville Irrigation District and local community.

5.3 Step 2 - Inventory and Forecast

5.3.1 Introduction

The following data is used to further define and characterize the problems and opportunities. Quantitative and qualitative descriptions are made for both current and future conditions and are used to define existing and future without-project conditions.

5.3.2 Inventory of Existing Conditions

Cartersville Dam is located at the town of Forsyth, Montana. The legal description of the site is: T67N R40E S14. The dam belongs to the Cartersville Irrigation District and was constructed during the early 1930's utilizing a rock- rubble riprap capped with concrete. The dam is over 800 feet in length and spans the entire channel of the Yellowstone River (Figure 5-1). The approximately 80-year old structure has experienced deterioration typical of aging dams and has required annual maintenance in recent years. The irrigation diversion dam has associated water rights dating to the late1800's.

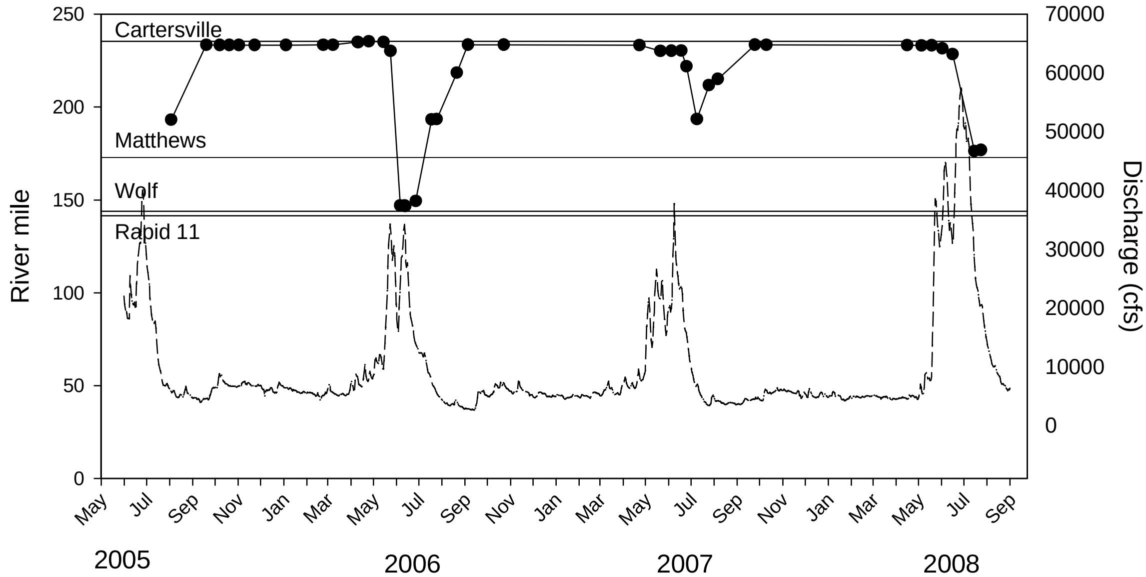
Figure 5-1 Cartersville Dam Viewed From the Right (South) Bank During Low Discharge.

Because this dam spans the entire river bed, it is viewed as a passage barrier to fish and boaters. The greatest passage impediment likely occurs during periods of lower flows (Bureau of Reclamation and Montana Fish Wildlife and Parks 1999). Radio telemetry data provided by Matt Jaeger of Montana Fish, Wildlife & Parks (Figure 5-2) shows examples of two shovelnose sturgeon that migrated upstream to the base of Cartersville Dam but did not pass upstream of the structure. Jaeger (unpubl. data) found that 13 out of 37 (35%) shovelnose sturgeon he monitored exhibited similar migration patterns affected by Cartersville Dam. These data clearly suggest Cartersville Dam is an upstream passage impediment to shovelnose sturgeon.

There are four more irrigation diversion dams above Cartersville, including the Yellowstone, Rancher’s Ditch, Waco-Custer, and Huntley diversions. Huntley has a side channel for fish passage and the other three diversion dams are relatively low, so they are likely to be navigable to fish at least during high flows when the diversions become submerged. The approximate number of river miles between the Cartersville and Yellowstone diversions is 56 miles. Consequently, the passage barrier at Cartersville effectively isolates as little as 56 miles of Yellowstone River channel, and as much as the entire river above Cartersville.

5.3.3 Future without Project Conditions

The following consequences may result if no action is taken to improve fish passage at Cartersville Dam.



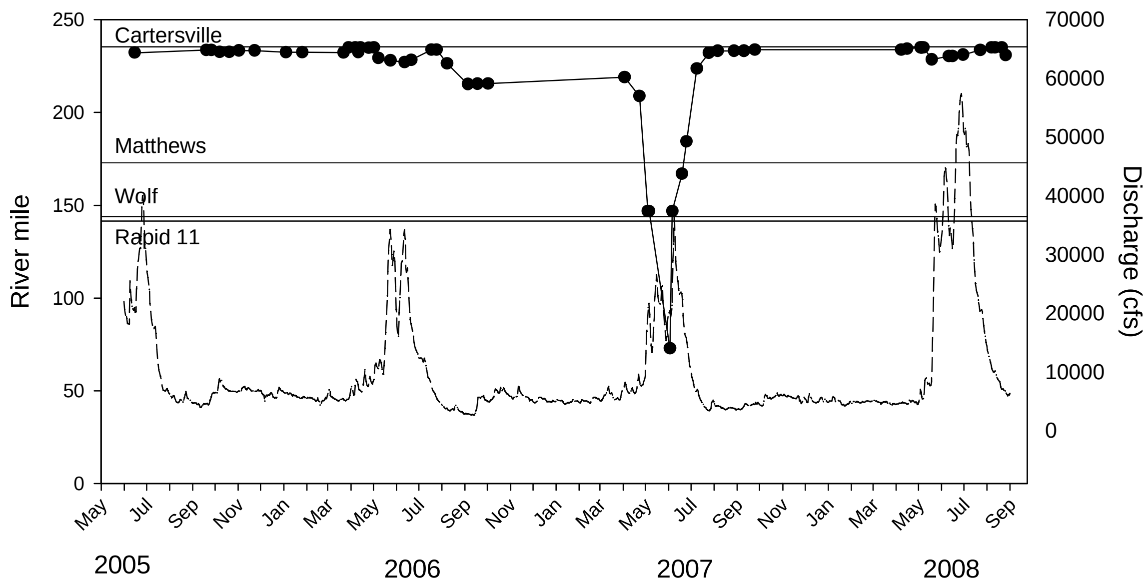


Figure 5-2 Movement of Shovelnose Sturgeon
Movements of shovelnose sturgeon number 420-27 (top figure) and 480-66 (bottom figure) in the Yellowstone River, 2005-2008. Sturgeon locations are indicated with black dots connected by a solid line; discharge at Miles City is displayed as a dashed line. Horizontal reference lines indicate the locations of Cartersville Dam and Matthews Rapid, Wolf Rapid, and Rapid 11 (M. Jaeger unpubl. data).

5.3.3.1 Water Supply

Dam is in poor condition. The dam crest has been eroded in numerous locations and a deep scour hole has developed at the toe. Additional rock has been added on a regular basis to protect the dam from failure. Failure would lead to loss of irrigation water and city water supply.

5.3.3.2 Conservation and Ecology

Persistence of habitat fragmentation caused by the passage barrier at Cartersville Dam has negative consequences for conservation of sturgeon and other fish and macroinvertebrates. Habitat fragmentation isolates populations of organisms, thereby limiting the exchange of genetic material. Over time, isolated populations become increasingly homozygous. Reductions in genetic variability through inbreeding reduce an organism's potential to adapt to changing environmental conditions or diseases. Over time, isolation also leads to genetic drift and ultimately to distinctly different populations.

Habitat fragmentation also reduces the long-term viability of populations isolated by Cartersville Dam. For example, extirpation of a subpopulation upstream of the dam (from any cause) would lead to an irreversible reduction in overall population size as the barrier would prevent repopulation of the upstream reaches. This reduces the long-term viability of the larger population by increasing its vulnerability to local extinctions.

Persistence of the barrier may cause indirect ecological consequences for other organisms as well. For example, changes in community composition (e.g. loss a particular species) can have indirect or cascading trophic effects on predator, prey, and competing species. This may lead to far-ranging shifts in community structure, especially in simple systems or when keystone species such as top predators are involved.

In conclusion, the barrier at Cartersville Dam will continue to cause habitat fragmentation, which leads to a loss of genetic variability, decreased population viability, and other indirect ecological consequences.

5.3.3.3 Public Safety

Dam presents a hazard to boaters, fishermen, swimmers. Sharp drop-offs such as these create hydraulic conditions that are difficult to escape.

5.3.3.4 Boat Passage

Currently, boat passage from access ramp to upstream reaches is not possible. Due to the sharp drop, the only way to move upstream past the dam is to portage.

5.4 Step 3 - Formulation of Alternative Plans

5.4.1 Introduction

Alternative plans address specific ways to achieve planning objectives within constraints, which solve the problems and realize the opportunities discussed earlier. An alternative plan consists of structural and/or nonstructural measures, strategies, or programs formulated to meet the identified study objective subject to constraints (USACE, 2000).

5.4.2 Pre-Design Site Assessment

5.4.2.1 Field Survey

A field survey was performed from which a topographic map of the Yellowstone River adjacent to the diversion dam could be developed (Figure 5-3).

Fishery and geomorphic team members also evaluated the dam site during the topographic survey.

5.4.2.2 Hydrology

The U.S. Geological Survey (USGS) has gage 06295000 Yellowstone River at Forsyth, Montana located approximately one mile upstream of the diversion dam (Figure 5-4). The statistics presented in Figure 5-4 describe the magnitude and frequency of flows to which the proposed project will be exposed.

5.4.2.3 Hydraulics

The existing conditions at the time of the survey were calibrated to two models; the USACE HEC-RAS model and River FLO-2D.

5.4.2.3.1 HEC-RAS

A HEC-RAS model was created using DOWL HKM field measured cross sections of the Yellowstone River at Forsyth, Montana. Cross section locations are shown on Figure 5-5. A divided flow option was used to model flow around the island downstream of Cartersville Dam. Stream flow at the time of the field survey of 6,500 cfs was obtained from the USGS gage Yellowstone River at Forsyth located approximately one mile upstream of the dam. The dam crest elevation could only safely be measured at the abutments. The measured crest elevation at south abutment was 2508.3 NGVD. The dam crest acts as a weir and is in disrepair, resulting in a variable crest elevation. The weir equation ($Q = CLH^{3/2}$) was used with the measured water surface elevations to estimate the average crest elevation of the dam. This analysis revealed that the weir coefficient (C) would be unrealistically high if the dam crest was elevation 2508.3 all the way across the 800 feet wide dam. A combination of the channel roughness coefficient (Manning's n) and the average dam crest elevation were adjusted to allow calibration of the model using reasonable parameters, yielding an estimated average crest elevation of 2507.8 (See Figures 5-6 and 5-7).

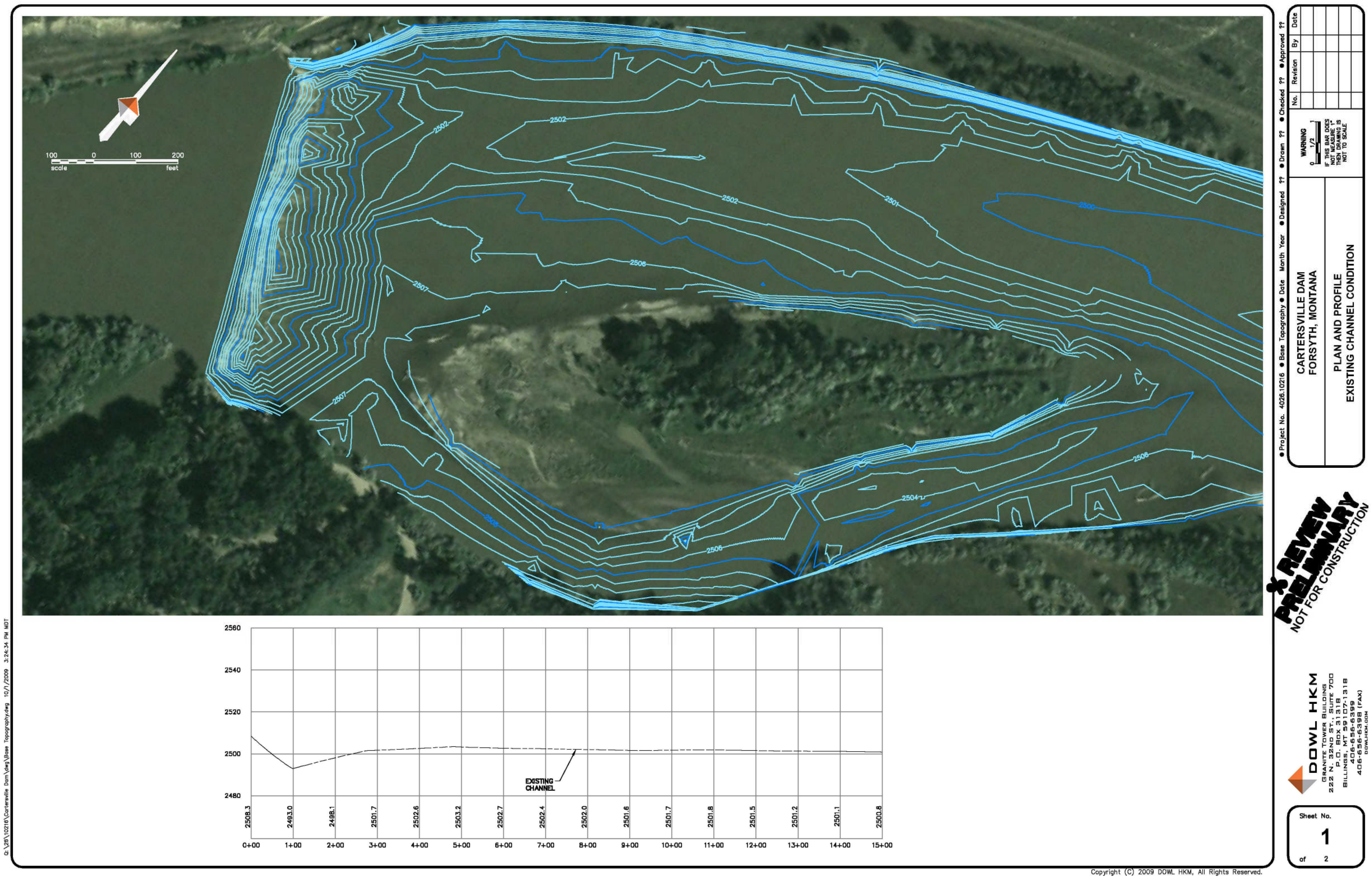


Figure 5-3 Plan and Profile of Existing Channel Condition

06295000 Yellowstone River at Forsyth, Mont.
Site Number 182

LOCATION.--Lat 46°15'58", long 106°41'24" (NAD 27), in NE¼NW¼NW¼ sec.23, T.6 N., R.40 E., Rosebud County, Hydrologic Unit 10100001, on right bank 0.3 mi downstream from U.S. Highway 12 bridge, at Forsyth, and at river mile 238.2.
DRAINAGE AREA.--40,146 mi^2.
PERIOD OF RECORD.--July 16, 1921, to September 30, 1923 (no winter records), October 1977 to current year (2002). Miscellaneous discharge measurements were made in 1974 to 1976 and are available in files of U.S. Geological Survey Montana District Office.
GAGE.--Water-stage recorder. Altitude of gage is 2,504.62 ft (NGVD 29), from nearby elevation determined by City of Forsyth. July 1921 to March 1922, nonrecording gage on discontinued highway bridge 10 ft downstream from gage at different datum. March 1922 to September 1923, nonrecording gage on discontinued highway bridge 10 ft downstream from gage at datum 2 ft higher.
REMARKS.--Diversions for irrigation of about 838,000 acres upstream from station. Flow regulated to some extent by Bighorn Lake, usable capacity, 1,312,000 acre-ft, on Bighorn River. Small diversion dam about 4,200 ft downstream from station. Bureau of Reclamation satellite telemeter at station.

Magnitude and probability of annual low flow based on 24 years of record

Period of consecutive days	Discharge, in ft^3/s, for indicated recurrence interval, in years, and non-exceedance probability, in percent					
	2	5	10	20	50	100
	50%	20%	10%	5%	2%	1%
1	3,230	2,320	1,920	1,640	--	--
3	3,460	2,520	2,100	1,800	--	--
7	3,880	2,970	2,560	2,260	--	--
14	4,630	3,620	3,090	2,670	--	--
30	5,150	4,100	3,520	3,050	--	--
60	5,460	4,400	3,820	3,340	--	--
90	5,890	4,780	4,170	3,670	--	--
120	6,200	5,040	4,420	3,910	--	--
183	6,610	5,240	4,530	3,980	--	--

Magnitude and probability of seasonal low flow from March-June based on 25 seasons of record

Period of consecutive days	Discharge, in ft^3/s, for indicated recurrence interval, in years, and non-exceedance probability, in percent					
	2	5	10	20	50	100
	50%	20%	10%	5%	2%	1%
1	5,200	3,600	2,830	2,250	1,690	--
3	5,320	3,760	3,000	2,440	1,880	--
7	5,460	4,060	3,400	2,900	2,390	--
14	5,900	4,610	4,030	3,590	3,150	--
30	6,260	4,850	4,240	3,790	3,340	--

Magnitude and probability of seasonal low flow from November-February based on 25 seasons of record

Period of consecutive days	Discharge, in ft^3/s, for indicated recurrence interval, in years, and non-exceedance probability, in percent					
	2	5	10	20	50	100
	50%	20%	10%	5%	2%	1%
1	3,350	2,360	1,930	1,650	1,320	--
3	3,630	2,600	2,140	1,820	1,450	--
7	4,080	3,200	2,790	2,480	2,160	--
14	4,650	3,760	3,330	2,990	2,630	--
30	5,250	4,410	3,970	3,610	3,230	--

Duration of daily mean flows based on 25 years of record

Discharge, in ft^3/s, which was equaled or exceeded for indicated percent of time							
99%	98%	95%	90%	80%	70%	60%	50%
2,560	3,110	3,660	4,420	5,190	5,970	6,780	7,610
40%	30%	20%	15%	10%	5%	2%	1%
8,440	10,300	13,500	16,700	23,200	32,000	43,200	48,800

Magnitude and probability of annual high flow based on 25 years of record

Period of consecutive days	Discharge, in ft^3/s, for indicated recurrence interval, in years, and exceedance probability, in percent					
	2	5	10	25	50	100
	50%	20%	10%	4%	2%	1%
1	41,500	57,300	69,100	85,500	99,000	--
3	39,600	54,000	64,000	77,200	87,400	--
7	36,100	49,500	58,900	71,400	81,300	--
15	33,300	45,500	53,900	65,000	73,600	--
30	30,000	40,500	47,500	56,400	63,100	--
60	25,300	33,800	39,300	46,100	51,100	--
90	21,100	28,000	32,300	37,600	41,500	--

Magnitude and probability of seasonal low flow from July-October based on 24 seasons of record

Period of consecutive days	Discharge, in ft^3/s, for indicated recurrence interval, in years, and non-exceedance probability, in percent					
	2	5	10	20	50	100
	50%	20%	10%	5%	2%	1%
1	5,520	4,030	3,300	2,740	--	--
3	5,630	4,080	3,330	2,760	--	--
7	5,790	4,180	3,410	2,830	--	--
14	5,970	4,280	3,480	2,880	--	--
30	6,230	4,450	3,650	3,060	--	--

Monthly and annual mean discharges

Month	Maximum (ft^3/s)	Minimum (ft^3/s)	Mean (ft^3/s)	Standard deviation (ft^3/s)	Years of record
October	10,700	3,520	7,490	2,120	25
November	10,500	4,190	6,990	1,700	25
December	8,930	3,620	6,110	1,190	25
January	7,800	3,240	5,720	1,120	25
February	10,200	3,510	6,140	1,590	25
March	15,100	3,220	7,060	2,530	25
April	13,300	4,220	7,720	2,340	25
May	27,800	10,000	17,300	4,270	25
June	63,700	10,000	29,800	12,000	25
July	34,400	6,140	18,300	8,680	25
August	17,600	2,740	8,150	3,590	25
September	11,300	2,720	6,960	2,370	25
Annual	17,600	6,030	10,600	2,630	25

Figure 5-4 USGS Gage Yellowstone R. at Forsyth (Scientific Investigations Rpt 2004-5266)

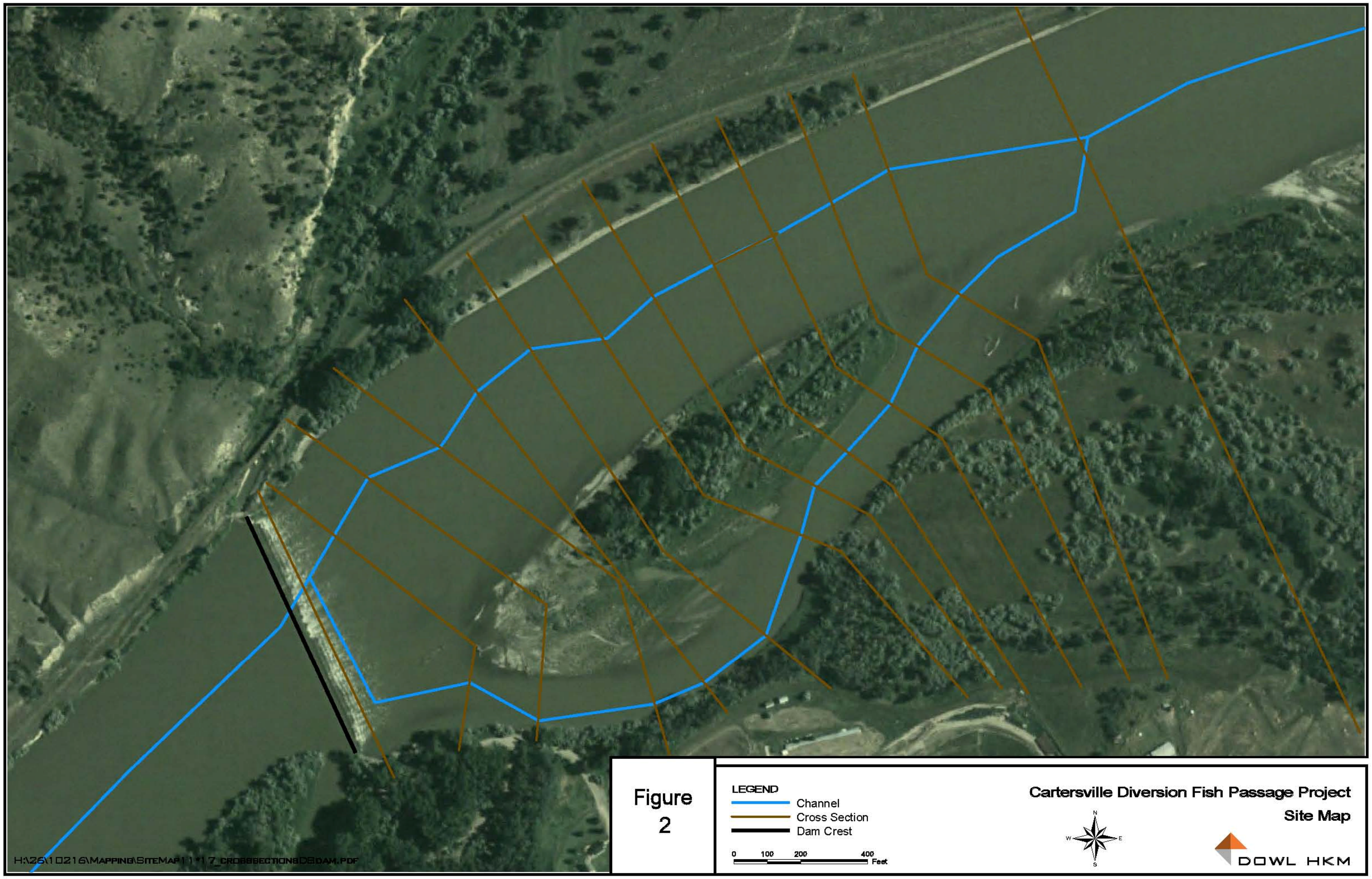


Figure 5-5 Surveyed River Cross Sections

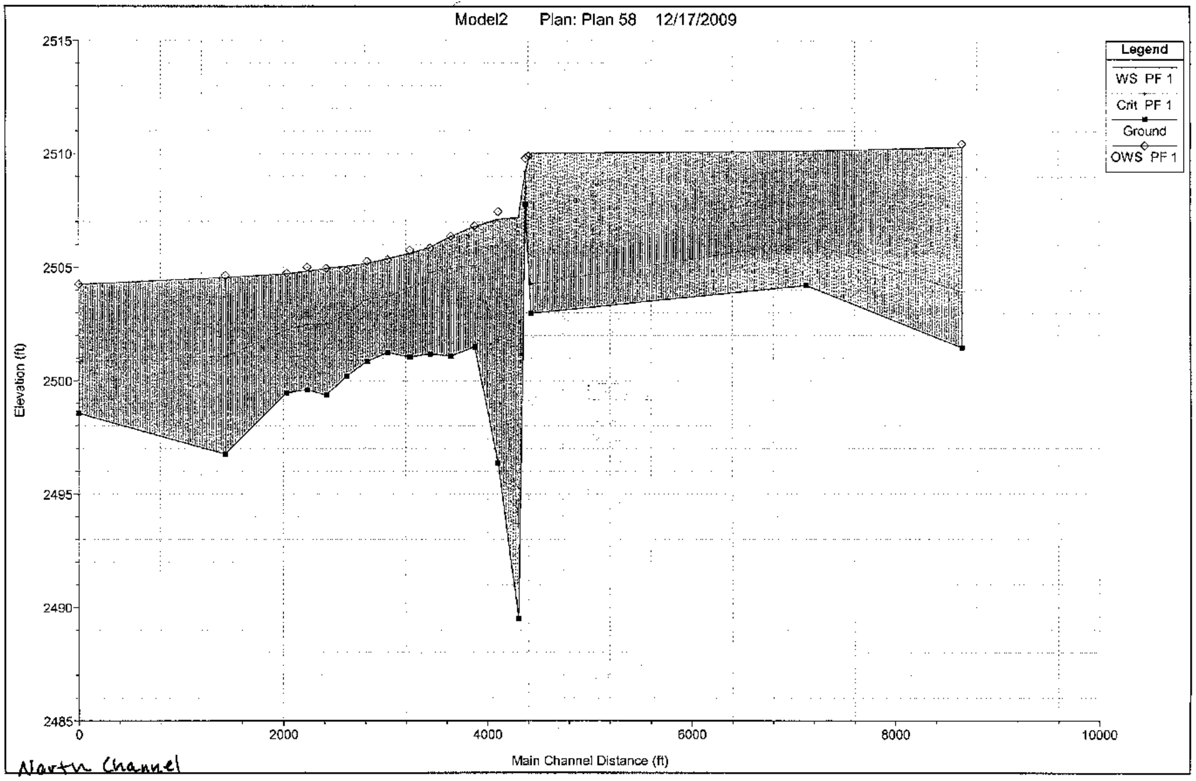


Figure 5-6 HEC RAS Calibrated Profile, North Channel

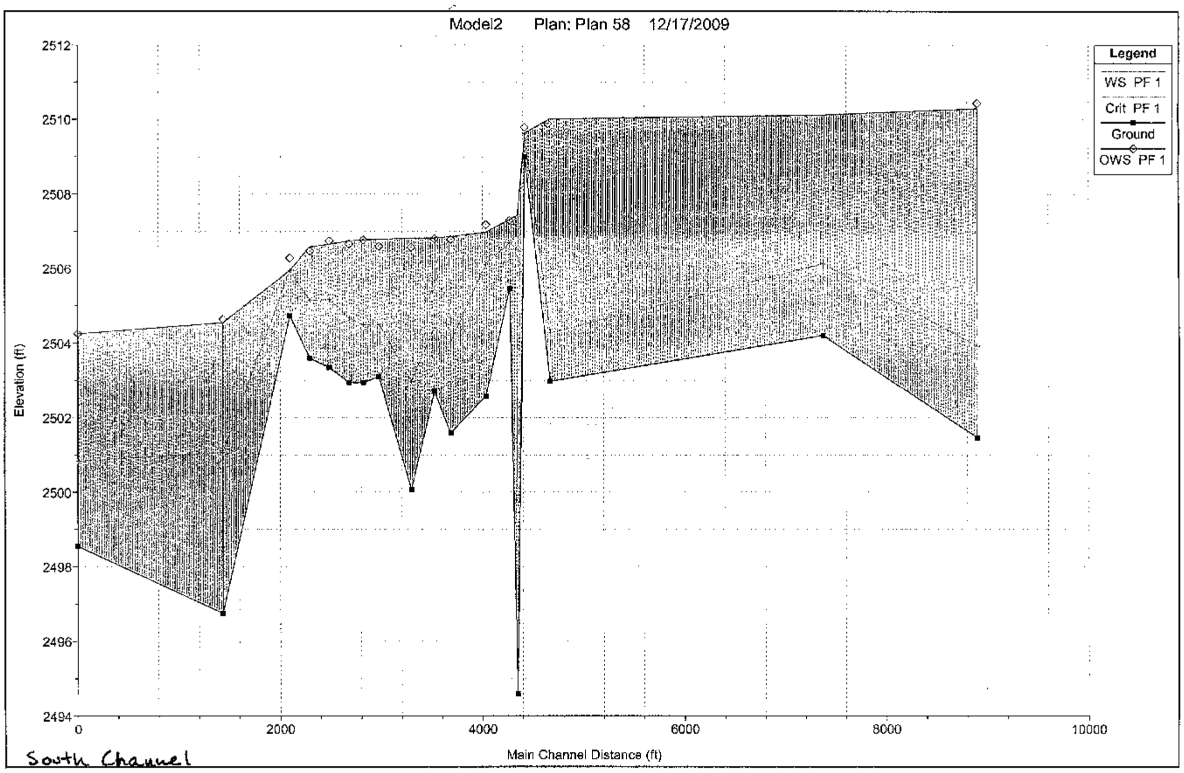


Figure 5-7 HEC-RAS Calibrated Profile, South Channel

5.4.2.3.2 River FLO-2D

The FLO-2D two-dimensional computer model was also utilized to model existing condition. Like HEC-RAS, the FLO-2D was able to match measured water surface elevations at a flow of 6500 cfs utilizing parameters within a reasonable range (Figures 5-8, 5-9, and 5-10). The velocities and depths for the existing conditions provide a comparison to proposed alternatives. The successful calibration indicates the FLO-2D model can be used to evaluate the proposed alternatives.

5.4.2.4 Floodplain

Federal Emergency Management Agency (FEMA) floodplain maps are available for the City of Forsyth and Rosebud County (Figures 5-11 and 5-12). Floodplain areas are mapped Zone A, which means the boundaries were developed by approximate methods and no base flood (100 year) water surface elevations have been determined.

5.4.3 Design Approach

The design for passage of fish and other aquatic organisms at dams can be defined in two general categories; geomorphic and hydraulic (Figure 5-13). Geomorphic design (stream simulation) is based on the premise that a channel that simulates characteristics of the natural channel will present no more of a challenge to movement of organisms than the natural channel. No part of the design is specifically directed at target species or their swimming capabilities (Bates and Love, 2009) (Figure 5-14). Alternatively, the more traditional approach of hydraulic design is based on specific fish passage design criteria that can include migration timing, swimming ability, and behavior of selected target species (Bates and Love, 2009).

> Stream Simulation Design: A channel that simulates characteristics of the natural channel, will present no more of a challenge to movement of organisms than the natural channel.

> Hydraulic Design: A structure with appropriate hydraulic conditions will allow target species to swim through it.

For this project, a combination of the geomorphic and hydraulic design approaches is being used. Reference reaches have been selected which are targeted to specific species, in this case shovelnose sturgeon. In addition to replicating the characteristics of the reference reaches, hydraulic conditions (e.g. depth and velocity) have been identified and replicated. Additional hydraulic design criteria have been developed based on laboratory testing performed by others and field studies.

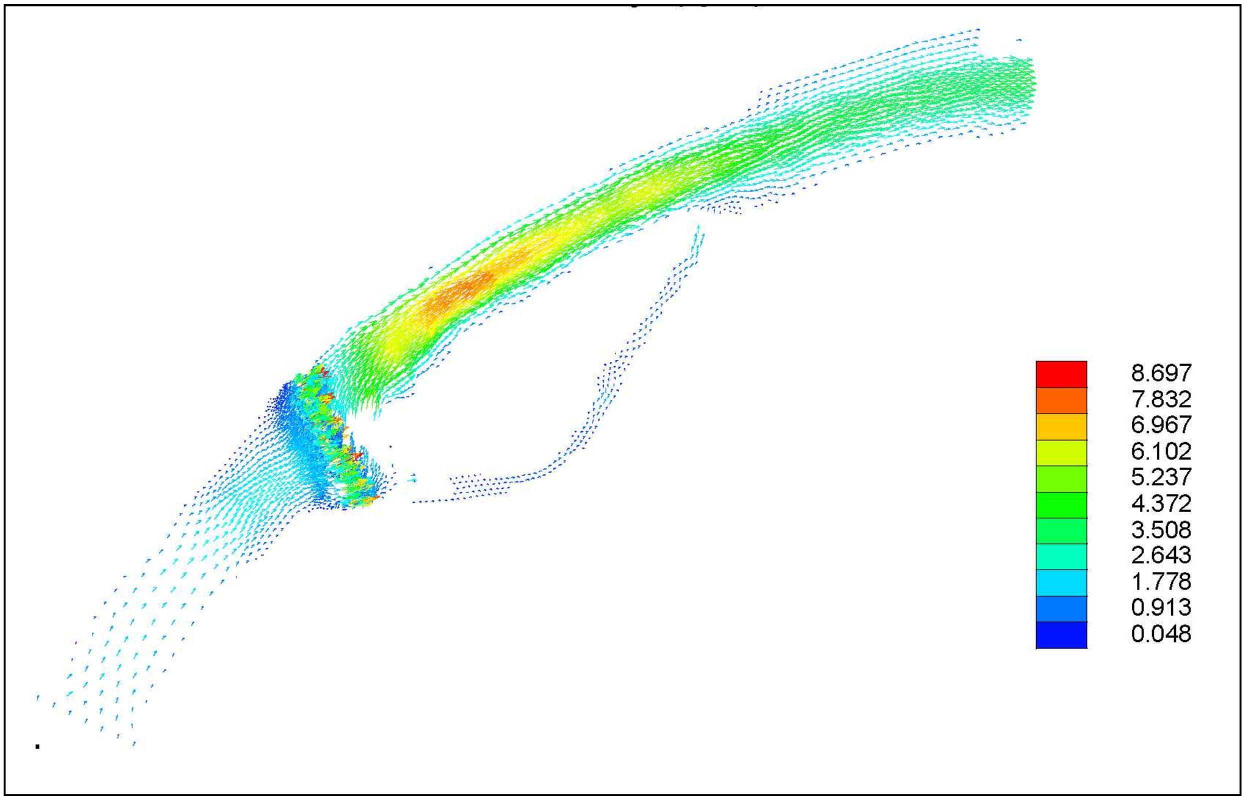


Figure 5-8 Existing Velocity (ft/s) Q = 6500 cfs

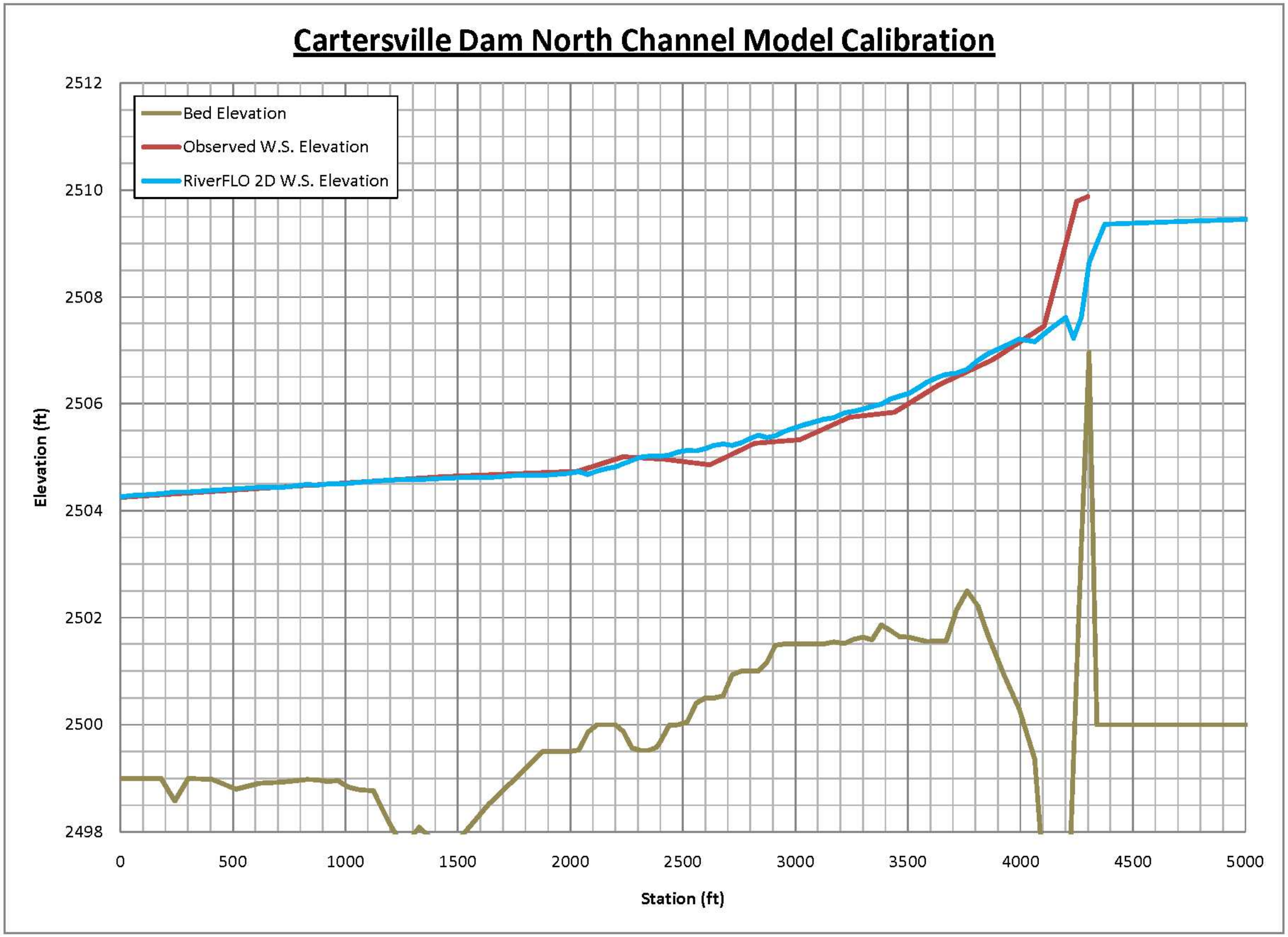


Figure 5-9 Cartersville Dam North Channel Model Calibration

Agreement between the observed (red line) and modeled (blue line) indicate the model is calibrated to field measurements.

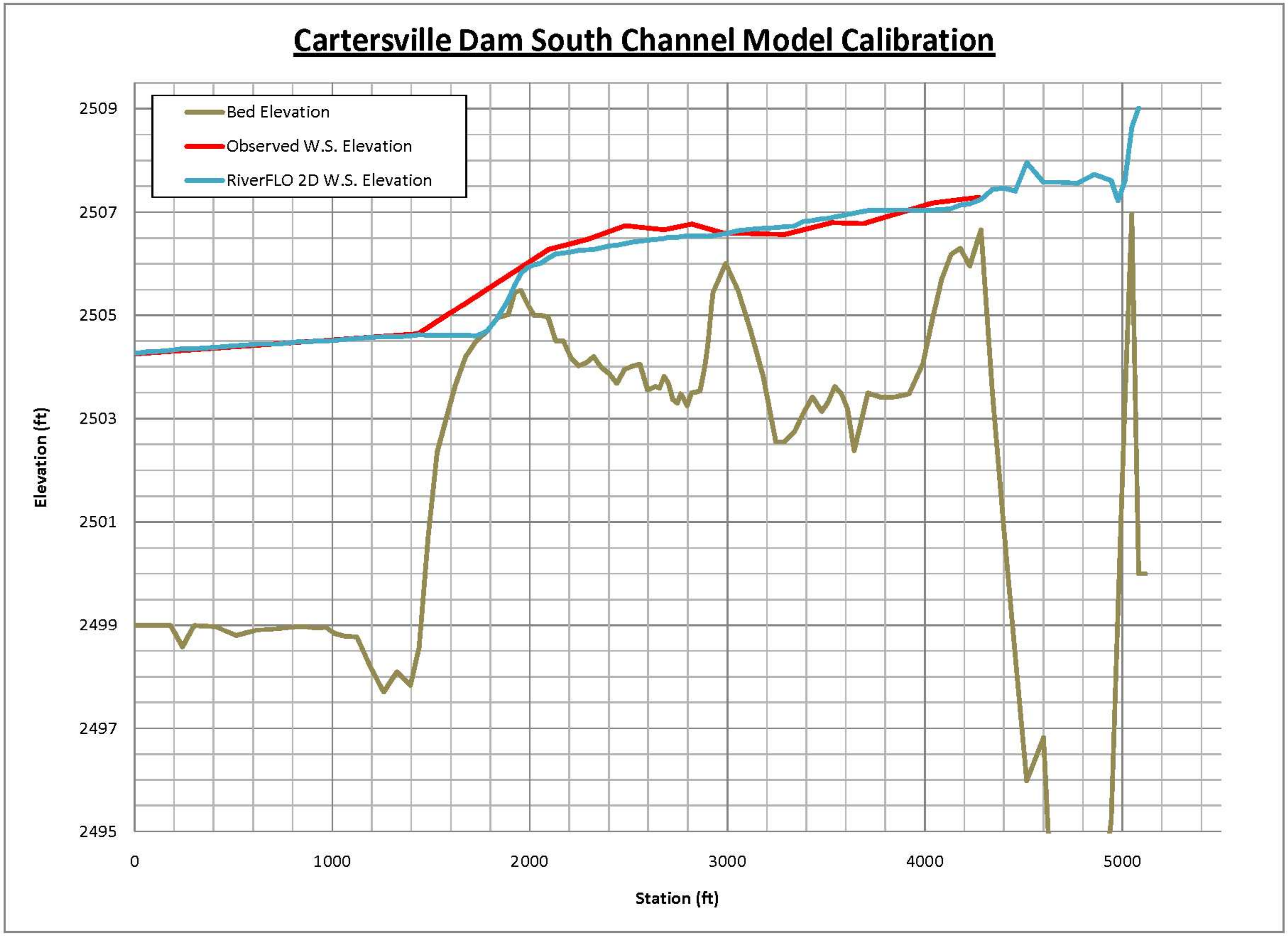


Figure 5-10 Cartersville Dam South Channel Model Calibration

Agreement between the observed (red line) and modeled (blue line) indicate the model is calibrated to field measurements.

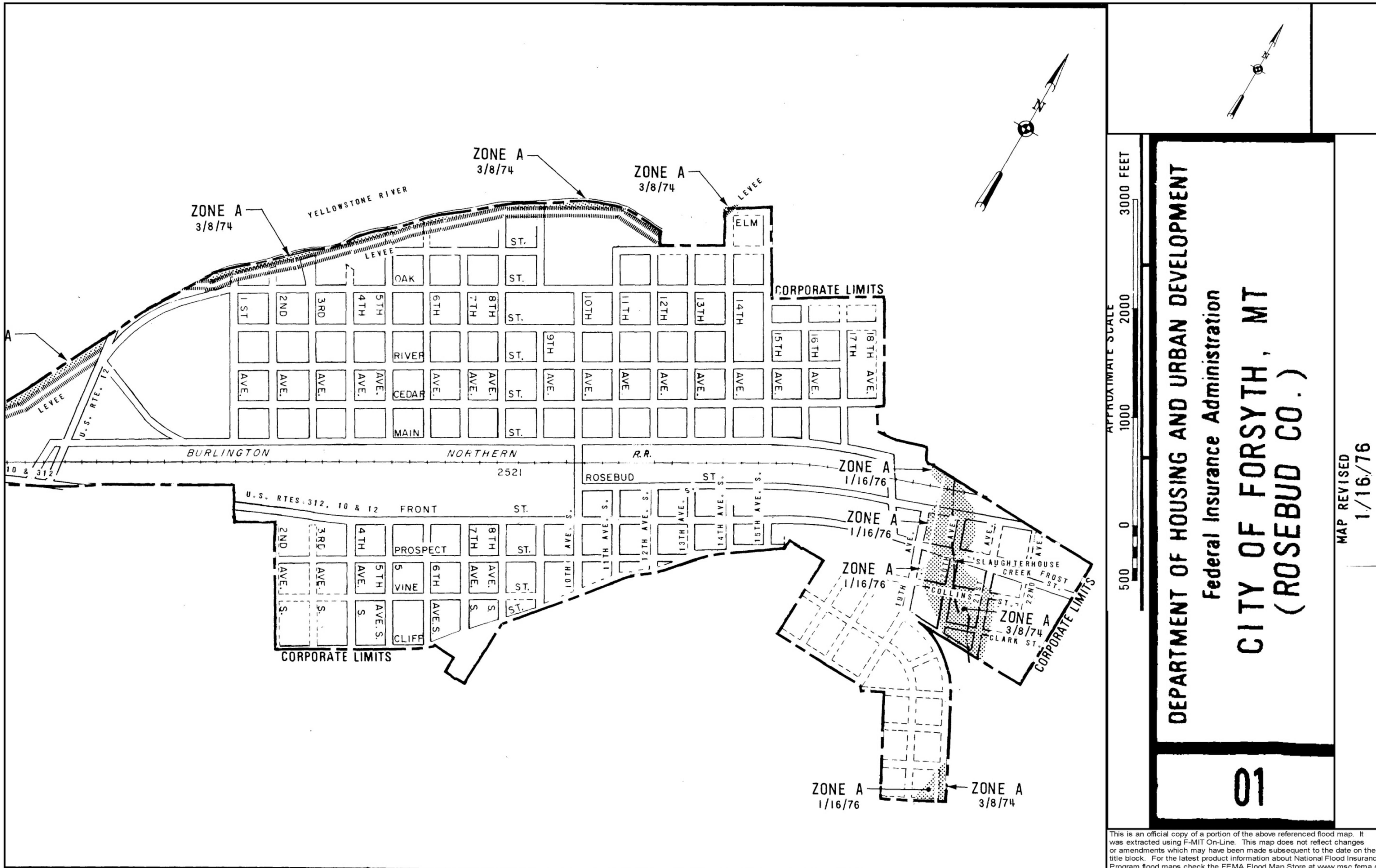


Figure 5-11 Floodplain Map for the City of Forsyth

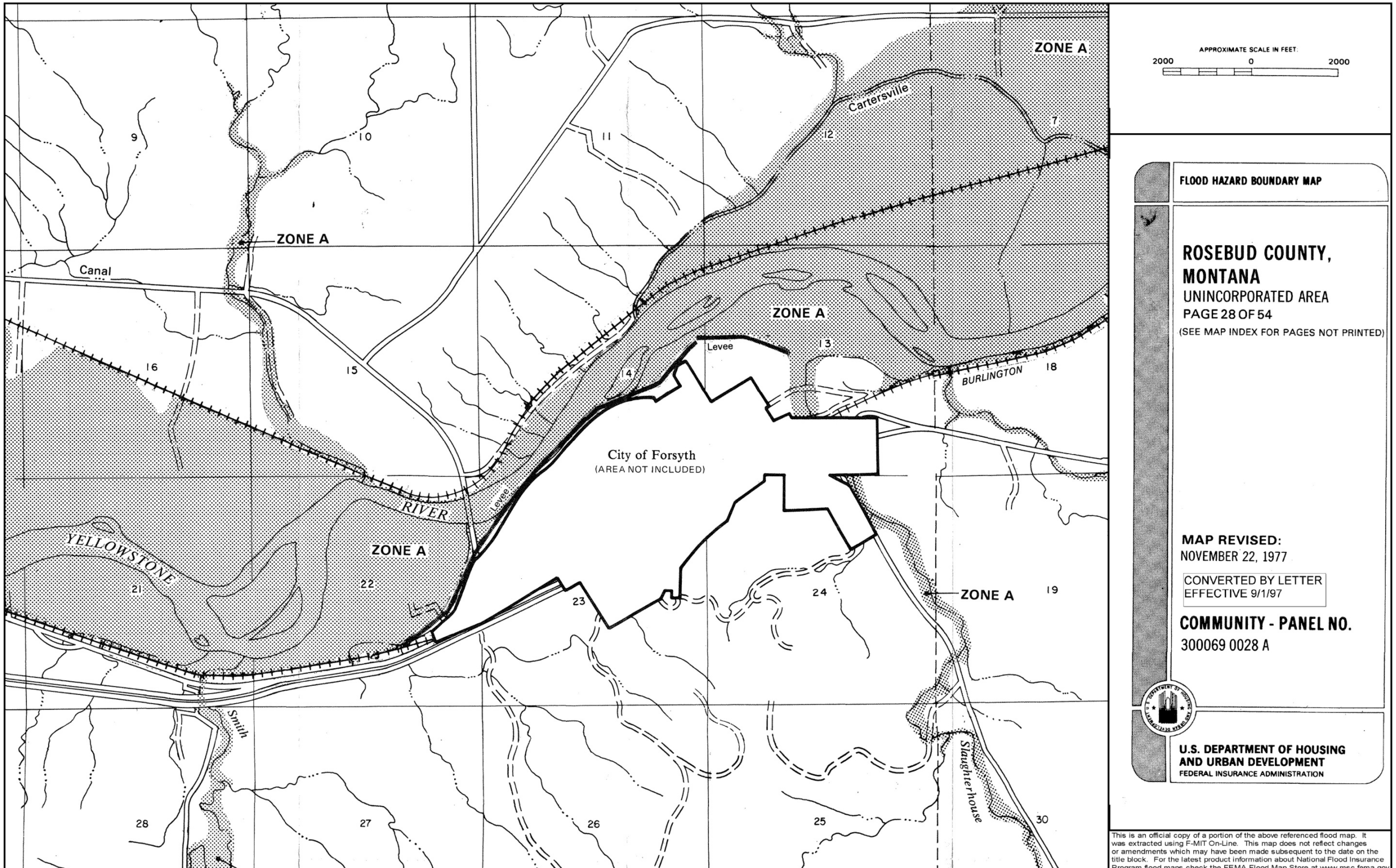


Figure 5-12 Floodplain Map for Rosebud County

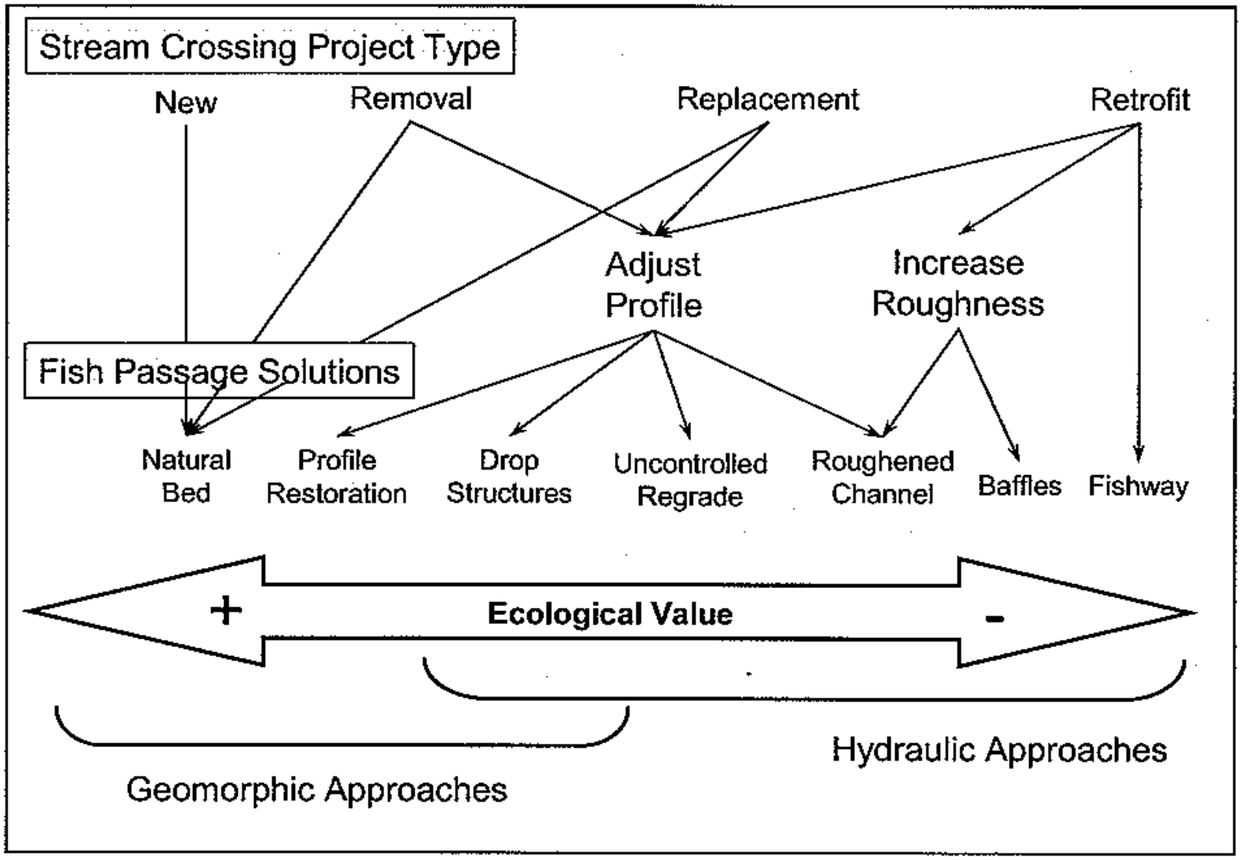


Figure 5-13 Solutions for Fish Passage

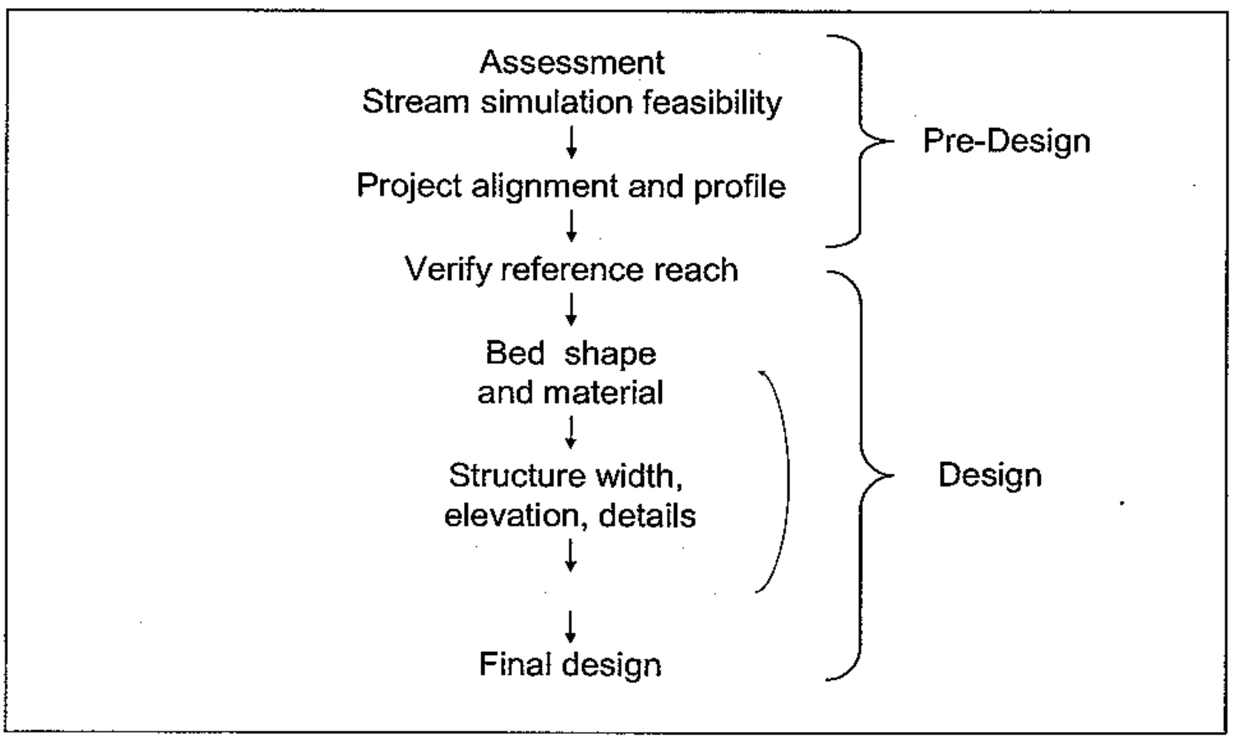


Figure 5-14 Stream Simulation (geomorphic approach) Process Flowchart

5.4.4 Sturgeon Swimming Abilities and Implications for Passage Design

The following section describes available information regarding the swimming abilities of sturgeon, both in the laboratory environment and on the Yellowstone River. In order provide for successful passage at Cartersville Dam, steep sections of the Yellowstone River where sturgeon passage events have been monitored are identified and assessed with regard to structure and hydraulics. These results are then combined to generate design guidelines for proposed alternatives that reflect conditions at these natural passage analogs that currently exist on the Yellowstone River.

5.4.4.1 Sturgeon Ecology and Swimming Behavior

5.4.4.1.1 Evolution, Distribution, Morphology

Sturgeons (Family Acipenseridae) are large, ancient fishes that occur in North America and Eurasia. The subfamily Scaphirhynchinae contains two genera; Pseudoscaphirhynchus, which occurs in Central Asia and Scaphirhynchus, which occurs in North America. The genus Scaphirhynchus is characterized by a flattened shovel-shaped snout; a long, slender, and completely armored caudal peduncle; prolonged upper lobe of the caudal fin; and the absence of a spiracle (Smith 1979). This morphology and features such as small eyes, a tough leathery skin (Cross and Collins 1975), dorsoventrally flattened body, and sensitive barbels are adaptations to a life in large, swift, and turbid rivers. Three species of Scaphirhynchus are known: pallid sturgeon (Scaphirhynchus albus), shovelnose sturgeon (S. platorynchus), and Alabama sturgeon (S. suttkusi). Pallid and shovelnose sturgeon occur in the Mississippi river basin, whereas Alabama sturgeon, only recently described, are found in the Mobile Bay Basin (Williams and Clemmer 1991).

shovelnose sturgeon
(IN Dept. of Natural Resources)

5.4.4.1.2 Life History

Shovelnose and pallid sturgeon are long-lived species, living up to perhaps 20-30 years or more. Adults do not spawn every year and spawning most likely takes place over hard substrates such as gravel or cobble (Keenlyne 1996). Following hatching of eggs, larval shovelnose and pallid sturgeon swim up above the bottom of the river such that they drift with the current and disperse downstream before they become benthically orientated (Kynard et al. 2002, Kynard et al. 2007, Braaten et al. 2008). Shovelnose sturgeon drift for about 6 days post-hatch whereas pallid sturgeon drift 11-17 days post-hatch (Braaten et al. 2008). Laboratory and field experiments with larval pallid and shovelnose sturgeon suggest that shovelnose sturgeon may drift 58 to 155 miles and pallid sturgeon may drift from 152 to 329 miles depending on water velocity and when the transition to bottom orientation occurs (Kynard et al. 2007, Braaten et al. 2008). The long reaches of unimpeded river required demonstrate the need to provide passage at structures that block sturgeon spawning runs.

5.4.4.1.3 Status

Shovelnose sturgeon are likely extirpated from three states, and are of some level of concern in eight states (Keenlyne 1996). Shovelnose sturgeon are not a species of special concern in Montana (Montana Natural Heritage Program 2009). Pallid sturgeon, although likely never abundant (Bailey and Cross 1954), have undergone severe declines throughout their range and were listed as an Endangered Species by the US Fish and Wildlife Service in 1990 (Dryer and Sandvol 1993).

5.4.4.1.4 Field Observations of Habitat Use

Observations of habitat use by shovelnose and pallid sturgeon in rivers are primarily obtained by use of radio telemetry equipment. In the Yellowstone and Missouri rivers, Montana and North Dakota, adult shovelnose sturgeon used current velocities (measured about 0.33 ft above the bottom of the river) of 0.07 to 5.0 feet/second (mean = 2.6 ft/s) whereas adult pallid sturgeon used current velocities of 0.00 to 4.5 ft/s (mean = 2.1 ft/s; Bramblett 1996; Bramblett and White 2001). Pallid sturgeon movements and habitat use were studied in Lake Sharpe, South Dakota using sonic telemetry (Erickson 1992). Lake Sharpe is an 85-mile segment of the Missouri River below Oahe Dam and above Big Bend Dam; the upper segment is riverine. Pallid sturgeon were most often found at bottom current velocities from 0 to 2.4 ft/s. Mean bottom velocities were 1.5 to 1.6 ft/s at juvenile pallid sturgeon locations and from 1.6 to 1.8 ft/s for shovelnose sturgeon locations in the Missouri River above Fort Peck Reservoir (Gerrity et al. 2008).

Shovelnose and pallid sturgeon are generally found at moderate to deep depths. Shovelnose sturgeon depths ranged from 3.0 ft to 33.1 ft and pallid sturgeon depths ranged from 2.0 to 47.6 ft in the Yellowstone and Missouri rivers (Bramblett 1996; Bramblett and White 2001). Depths at pallid and shovelnose locations were shallower in the Missouri River above Fort Peck reservoir (Gerrity et al. 2008), and in the Kansas River (Quist et al. 1999), but were deeper at sturgeon locations in the Missouri River in South Dakota (Erickson 1992), and in the Mississippi River (Hurley et al. 1987; Curtis et al. 1997). The differences in depth at these sturgeon locations are likely due to differences in local availabilities of depths. Both shovelnose and pallid sturgeon use the deepest half of the channel cross-section most often (Bramblett and White 2001).

Shovelnose sturgeon have been observed using substrates ranging from silt to boulder (Hurley et al. 1987; Bramblett 1996; Quist et al. 1999; Bramblett and White 2001; Gerrity et al. 2008). In the Yellowstone and Missouri rivers, Montana and North Dakota, 69.2% of shovelnose sturgeon locations were over gravel and cobble substrates, 26.6% were over sand, and 3.0% were over boulder (Bramblett 1996); the use of gravel and cobble and sand were not significantly different from their availability, but the use of boulder substrate was less than availability (Bramblett and White 2001). Shovelnose sturgeon used gravel and cobble substrates significantly more than pallid sturgeon whereas pallid sturgeon used sand significantly more than shovelnose sturgeon (Bramblett and White 2001). Most studies document that pallid sturgeon are largely associated with sand substrate (Bramblett 1996; Bramblett and White 2001; Gerrity et al. 2008), which likely coincides with their large-river distribution. However, hatchery-produced juvenile pallid sturgeon stocked into the Yellowstone River above Intake, Montana have maintained their positions in gravel/cobble-dominated reaches (Matt Jaeger, Montana Fish, Wildlife, and Parks, personal communication), rather than moving downstream to below Sidney, Montana where sand is the predominant substrate (Bramblett and White 2001).

5.4.4.1.5 Macrohabitat

Both shovelnose and pallid sturgeon occur in the Mississippi and Missouri River basins. However, whereas pallid sturgeon are largely limited to the mainstems of the Mississippi and Missouri rivers and the lower portions of a few large tributaries, shovelnose sturgeon occur in both mainstem habitats and large tributaries such as the Red, Arkansas, Ohio, upper Mississippi, and Yellowstone rivers (Bailey and Cross 1954; Lee et al. 1980).

In the Yellowstone and Missouri Rivers in Montana and North Dakota, channel widths at shovelnose sturgeon locations varied from 82 to 2,624 m and were significantly narrower than at pallid sturgeon locations, where width varied from 361 to 3,608 (Bramblett and White 2001). The channel pattern at shovelnose and pallid sturgeon locations was primarily sinuous or irregular; but pallid sturgeon rarely used straight channels and irregular meanders whereas shovelnose sturgeon observations were more evenly distributed among channel types. Both species were most often located near islands or bars. Pallid sturgeon appeared to use more dynamic reaches; as seral stage of islands and bars near pallid sturgeon locations was most often a sere preceding mature cottonwoods. Pallid sturgeon selected reaches with frequent islands and avoided reaches with fewer islands; shovelnose sturgeon were more generalized in channel use with respect to islands (Bramblett and White 2001). In the Missouri River above Fort Peck Reservoir, shovelnose and juvenile pallid sturgeon avoided reaches with islands and selected reaches without islands (Gerrity et al. 2008). The differences in island use in the two study areas may be related to depth; the areas around islands in the Missouri River above Fort Peck Reservoir were shallower than those in area studied by Bramblett and White (2001).

Radio-tagged shovelnose sturgeon were observed in the Yellowstone River (Matt Jaeger, Montana Fish, Wildlife, and Parks, unpublished data). During spring, channel crossovers were preferred, secondary channels were avoided, and other habitats used proportional to availability. During the runoff period and summer, secondary channels were avoided; other habitats were used proportional to their availability. During winter, crossovers and secondary channels were avoided and other habitats were used in proportion to their availability. Diversion dam pools (Cartersville and Intake) were preferred in spring and summer, likely because diversion dams blocked upstream movement.

5.4.4.1.6 Movements and Home Range

Both shovelnose and pallid sturgeon are capable of rapid, long-distance movements in unimpeded river reaches (Schmulbach 1974; Moos 1978; Bramblett and White 2001; Matt Jaeger, Montana Fish, Wildlife, and Parks, unpublished data). Range of activity is largest in spring and summer, and movements decrease into fall and winter. Shovelnose sturgeon ranges averaged 18.0 miles in spring, 32.7 miles in summer, 8.9 miles in fall, and 0.6 miles in winter (Bramblett 1996). Shovelnose sturgeon movements averaged 0.6 miles/day, and ranged up to 9.3 miles/day. Pallid sturgeon ranges averaged 23.9 miles in spring, 29.0 miles in summer, 14.3 miles in fall, and 0.6 miles in winter (Bramblett 1996). Pallid sturgeon movements averaged 1.0-1.2 miles/day, and ranged up to 13.3 miles/day. In the Yellowstone River, shovelnose sturgeon movements were highest in spring and runoff (to > 2.5 miles/day), moderate in summer (to > 1.2 miles/day) and fish were relatively sedentary in winter (Matt Jaeger, Montana Fish, Wildlife, and Parks, unpublished data).

5.4.4.1.7 Laboratory Trials of Swimming Ability

Observation of swimming behavior and trials of swimming abilities have been conducted for adult and juvenile, hatchery-produced and wild-caught shovelnose and pallid sturgeon in laboratory settings (Adams et al.1999; White and Mefford 2002; Adams et al. 2003). These studies have demonstrated that shovelnose and pallid sturgeon have an affinity for the bottom of the test chamber and can maintain their position in flowing water by appression or “station-holding” (i.e., maintaining position while in contact without active swimming). The morphology of shovelnose and pallid sturgeon (specifically the broad pectoral fins, broad shovel-shaped head, and flat ventral surface) creates negative lift that presumably allows fish to maintain position without expending energy. Other swimming behaviors observed in the laboratory included substrate skimming, where the ventral surface is in contact with the bottom with propulsion generated by body and caudal fin undulation, and free swimming, where swimming occurs in the water column without contact with the substrate (Adams et al. 1999; Adams et al. 2003).

Free swimming is used less as velocities increase; juvenile shovelnose and pallid sturgeon used free swimming < 18 % of the time at current velocities > 0.50 ft/s. Hatchery-reared pallid sturgeon had maximum sustained (i.e., > 200 minutes) swimming speeds of 0.8 and 0.3 ft/s for large (6.7 – 8.0 inches FL) and small (5.2 – 6.6 inches FL) size groups, respectively. Burst (i.e., < 30 second) rates were 1.81-

2.30 and 1.31-2.30 ft/s for large and small size groups, respectively (Adams et al. 1999). In separate swimming trials (Adams et al. 2003), demonstrated that the mean 30-minute critical swimming speeds of hatchery-reared juvenile shovelnose and pallid sturgeon were 1.21 ft/s and 1.18 ft/s, respectively; these speeds were not significantly different. This suggests that under temperatures similar to the test conditions (50-68°F), juvenile shovelnose and pallid sturgeon probably do not segregate in rivers due to differing swimming abilities.

White and Mefford (2002) used experimental flumes and fishways to assess the swimming ability of 26 adult shovelnose sturgeon collected in July 2001 from the Yellowstone River. Fork lengths of experimental sturgeon ranged from 25.2 to 35.8 inches and weight ranged from 3.1 to 10.6 pounds. The swimming study had two phases. The first phase identified behavior of sturgeon exposed to a combination of flow depth, bed roughness, velocity, and turbulence (i.e., vertical and horizontal baffles) in a 3 by 30-foot flume and in a 3 by 60-foot adjustable-slope flume. Preliminary testing indicated that water depth in the flumes had no observable influence on sturgeon behavior, so depth was not manipulated in flume tests. The second phase observed the response of sturgeon to three types of fishways: a standard vertical slot baffled fishway, a dual-vertical slot baffled fishway, and a rock channel with boulder weirs.

Success rates for sturgeon negotiating the 30-foot flume with substrates ranging from sand to cobble increased with flow velocity to 3.0 ft/s and decreased slightly at velocities of 3.5 and 4.0 ft/s (67% at 0.8 ft/s, 83% at 1.2 and 1.6 ft/s, 100% at 2.0, 2.5, 3.0 ft/s, 92% at 3.5 ft/s, and 87% at 4.0 ft/s). Substrate type appeared to have little effect on fish passage, although cobble substrate may have reduced success at the highest velocities. At low velocities, fish were less oriented towards flow and milled around, moving up and down channel. Attraction velocities became strong at 2.0 ft/s and remained high to 4.0 ft/s. Down-channel movement was most common and more often headfirst at the slowest two velocities. Down-channel movement at higher velocities was all tail-first. Average time required to reach the top of the flume was shortest at 4.0 ft/s (0.8 minutes) and longest at 0.8 ft/s (8.8 minutes).

White and Mefford (2002) reported results of shovelnose sturgeon swimming abilities in terms of average water column velocity. However, they also measured and reported vertical velocity profiles. Velocities were reduced near the bed of the flume and the reduction in velocity increased with bed roughness. The boundary layer was most apparent in the first four inches above the bed. For example, in the 4 ft/s trial with a cobble bed, velocity at 2 inches above the bed was about 2.6 ft/s, at 4 inches above the bed velocity was about 3.2 ft/s, and at 6 inches above the bed, velocity was about 4 ft/s. White and Mefford (2002) do not explicitly discuss the position of test sturgeon in the water column. However, because sturgeon normally swim or station-hold along the bottom of their habitat (Adams et al. 1999), the water velocities that test fish experienced at the scale of microhabitat were likely slower than mean water column velocities. Consequently, measurements of average current velocity may not be reflective of the slower microhabitat velocity sturgeon experience near the bed substrate. This is true for fish swimming in natural river beds as well.

Vertical baffles (15.5-inch and 22.5-inch) reduced successful flume negotiation overall, and successful passage decreased with baffle width. Overall percent of fish successfully negotiating the flume was 70% with 15.5 inch baffles (at average velocities ranging from 0.8 ft/s to 4.0 ft/s) whereas overall percent of fish successfully negotiating the flume was 40% with 22.5 inch baffles (at average velocities ranging from 0.8 ft/s to 4.0 ft/s). With the 22.5 inch baffles, sturgeon often circled in the eddy below the first baffle, and were often disoriented at velocities of 3 ft/s and higher.

Horizontal weir baffles of 4 heights ranging from 3 inches to 21 inches reduced successful passage from 12% to 53% relative to passage rates over sand to cobble substrates at the same water velocities without baffles. Although some fish negotiated all baffles tested, higher baffles reduced successful passage more than lower baffles. For example, overall passage (with velocities ranging from 0.8 to 4.0 ft/s) with 3-inch baffles was 78%, whereas it was 56% with 12-inch baffles, and 12.5% with 21-inch baffles. Most of the tested sturgeon that made it to the top of the flume did so immediately, rather than resting along the way, except with the 21-inch baffles, where only 2 of 16 fish successfully negotiated the flume. Orientation to flow was weak at 0.8 and 1.6 ft/s and strong at velocities of 2.0 ft/s and above.

A 60-foot, adjustable slope flume was used to test fish movement at velocities up to 6.5 ft/s, with smooth (plywood), coarse sand, gravel, and cobble substrates. Mean water velocities varied along the length of the flume because velocity increased as water moved down the flume. Water velocities also varied vertically. Water velocities decreased approaching the bed of the flume. For example, over a cobble bed with velocities at about 6 ft/s at 5 inches above the bed, velocity was about 2.6 ft/s at 2 inches above the bed. The near-bed decrease in velocity increased with increasing bed roughness. Overall passage success (all substrates) was 50-57% at the lowest two velocities (0.8 – 2.0 ft/s), and increased to 81% at 2.0 to 3.3 ft/s, before decreasing to 47% at 2.2-6.0 ft/s. Movement success was best over the smooth substrate (60-90%) and declined with increasing substrate size (25-50% over cobble). Sturgeon usually reached the top of the 60-foot flume in three or four spurts, resting for up to 3 minutes, apparently without effort, in maximum facing velocities (about 4 inches off the bed) of 6.5-7.8 ft/s. Fish usually rested no more than 3 minutes between “sprints”.

Shovelnose sturgeon passage and behavior was observed in three test fishways; a standard vertical slot baffle, a chevron-shaped dual-vertical-slot baffle (both were 5.5 ft wide by 5.5 ft deep, with a 5% bottom slope, baffles were spaced 6 ft apart), and a rock-lined bypass channel with boulder weirs (70 ft long, rock-lined trapezoidal channel, 2% slope, 4 ft wide by 4 ft deep, constructed of rip rap, 2-3.5 ft artificial boulders placed in an upstream-facing chevron). Fishway tests were conducted on shovelnose sturgeon collected from the Yellowstone River in October 2001; these fish were generally less motivated to move than the group of fish collected in July. Two of eight fish passed all four slots in the vertical baffle fishway. Fish activity increased as velocity increased, and the fish that passed in the shortest time (4 minutes) avoided the eddies behind the baffles. Two of 10 fish successfully passed all four baffles in the dual-slot fishway, although fish appeared to be more motivated to pass this fishway than in the standard vertical slot baffle fishway. Of the three fishway designs, fish passage was best in the rock fishway. Water velocities in the rock fishway ranged up to 3.3 to 4.4 ft/s. Fifteen of 24 (62.5%) shovelnose sturgeon successfully negotiated the fishway in times ranging from 14 to 83 minutes. Passage rate may have been higher with motivated fish; seven fish were not motivated to move and remained near the bottom of the fishway throughout the tests. Sturgeon that appeared to be motivated to move had no difficulty passing the rock fishway. The movement pattern of tested sturgeon in the rock fishway was very consistent; most fish chose the same route and were able to maintain station in facing velocities of 4 ft/s. Fish appeared to search for and follow the best hydraulic conditions for passage.

In summary of White and Mefford's (2002) shovelnose sturgeon swimming trials, fish successfully negotiated average velocities ranging from 0.8 to 6.0 ft/s, and all substrates ranging from sand to cobble. Passage declined somewhat with increasing substrate grain size, but even over cobble substrate, overall passage was 81%. Fish showed poor orientation to average velocities less than 2.0 ft/s; fish were strongly oriented to flow at velocities of 2 to 6 ft/s. Passage success declined substantially from 81-87% at 4 ft/s to 47% at 6 ft/s. Depth of water did not affect sturgeon behavior in the range tested (0.7 to 4.5 ft). Sturgeon negotiated horizontal and vertical eddies, but larger eddies caused delays in fish passage, and eddies were not needed for fish to successfully pass test flumes. Fish collected from the Yellowstone River in October, and used in the fishway tests appeared to be less motivated to move, nonetheless fishway tests were useful. Fish passage was poor in the standard vertical-slot fishway and in the dual-slot fishway; however fish passage was much improved in the rock fishway.

White and Mefford (2002) recommend attraction flows of 2-4 ft/s, a depth of 4 ft, and a uniform transition from fishway flow to downstream flow. Passage velocity should be 3-4 ft/s, and a rock channel fishway should be used, because of positive results with shovelnose sturgeon. For example, the rock fishway tested by White and Mefford (2002) was constructed of rip rap with 15% of rock < 5 inches and 85% < 15 inches, with 2 to 3.5 foot boulder placed in an upstream-facing chevron, with 2-foot gaps between the boulders. The boulders certainly created a diversity of velocities as well as some turbulence. Although results from baffle test in flumes indicate that turbulence may reduce sturgeon passage success, sturgeon were fairly successful at negotiating the fishway. Moreover, large boulders placed in a rock fishway would provide a diversity of velocities that would likely allow other fish species to pass the structure. However, large eddies that may mask attraction flow should be avoided. The study by White and Mefford (2002) and their recommendations probably provide the best inference for designing the fish passage structure at Cartersville for several reasons. The target species for passage at Cartersville is shovelnose sturgeon, which is the species that they tested. The fish were wild-caught from the Yellowstone River as opposed to hatchery-reared and they were adults. Their test flumes and fishways were of a relatively large size which enhances the inference and certainty of extrapolating from laboratory tests to field conditions.

5.4.4.2 Identification of Yellowstone River Slope Anomalies and Potential Rock Ramp Design Analogs

As described above, radio telemetry studies recorded shovelnose sturgeon passage through steep segments of the Yellowstone River downstream of Cartersville Dam. In order to support the design of a rock ramp passage structure at Cartersville Dam, these natural "rapids" were coarsely identified through an analysis of water surface slope from Cartersville Dam to the Missouri River. From these data, two notably steep passage areas were assessed as potential design analogs.

5.4.4.2.1 Identification of Slope Anomalies

Naturally steep segments of the Yellowstone River downstream of Cartersville Dam were initially identified by creating a LiDAR-generated water surface profile of the river centerline. A GIS project developed as part of the Yellowstone River Cumulative Effects Study (CES) includes a digitized centerline and river mileage reference dataset from the river mouth to Gardiner, Montana. In addition, LiDAR survey data of the river corridor includes water surface elevations at the time of the survey. To assess general river gradient downstream of Cartersville, the centerline was attributed with LiDAR-derived elevation data. Elevation points were applied to the centerline every 100 feet. This effort produced approximately 14,000 water surface elevation data points from RM 238 (Cartersville Dam at Forsyth) to RM 0. Water surface slope was then calculated at these 100-ft increments, and additional gradient calculations were made for 200, 400, 600, 1000, and 2000 ft centerline distances. The results were further screened to identify areas where channel lengths in excess of 400 feet have a slope of 0.3% or greater. These sites were tagged in the GIS and evaluated with air photos to assess their geomorphic context.

In addition to the slope assessment, potentially steep areas were identified using both air photos and historical references. Lewis and Clark described "rapids" on the river, and later accounts of these rapids are available. The rapids have been named, and attempts have been made here to apply the historic name to the feature. However, as some of the descriptions of rapid locations are vague, it is possible that the names used here do not correlate to other sources. Consequently, all features described herein are also identified by river mile.

5.4.4.2.2 Site Identified as Potential Analogs

A total of eleven sites were identified as having anomalously steep water surface profiles over several hundred feet of channel length (Table 5-1). These include a long series of bedrock rapids formed in the Fort Union Formation between Miles City (RM 183) and Kinsey (RM 167). These rapids are collectively referred to as the “Buffalo Shoals”. Matthews Rapid, located just downstream of Sunday Creek at the Matthews Recreation Area, is within this long series of bedrock exposures. Bear Rapid is located downstream, approximately 4.5 miles upstream of the Powder River at the mouth of Camp Creek. Wolf Rapid is located approximately 3 miles downstream of the Powder River, and Site 11 is 2 miles further downstream. All of these sites appear to have some bedrock influence, and the valley wall geology in this area is comprised of the Tullock Member of the Tertiary-age Fort Union Formation. This unit consists of interbedded sandstone, shale, mudstone and well indurated limestone (Vuke et al, 2001).

Table 5-1
Potential Reference Reaches

Site	Name	River Mile	Max 100-ft Slope
1	Uppermost Buffalo Shoals	184.0	0.26%
2	Buffalo Shoals above Sunday Cr	179.6	0.15%
3	Buffalo Shoals above Sunday Cr	178.2	0.18%
4	Buffalo Shoals above Sunday Cr	176.7	0.44%
5	Buffalo Shoals at Alkali Cr above Sunday Cr	176.0	0.21%
6	Buffalo Shoals just below Sunday Cr ("Matthews Rapid")	174.2	0.47%
7	Buffalo Shoals just upstream of railroad bridge	172.6	0.24%
8	Buffalo Shoals just downstream of railroad bridge	170.8	0.25%
9	Bear Rapid	153.4	0.39%
10	Wolf Rapid	146.0	0.37%
11	Unknown	144.0	0.58%

The results of this screening effort based on slope and length of slope indicated that the best potential reference riffles appear to be located at Matthews Rapid (RM 174.2), and Wolf Rapid (RM 146.0). Site 4 and Site 11 also showed promise as potential references, although they both have flow splits on the 2007 imagery. Based on overall slope and length, Matthews Rapid and Wolf Rapid were selected for further analysis.

5.4.4.2.3 Geomorphology of Matthews and Wolf Rapids

5.4.4.2.3.1 Matthews Rapid

Matthews Rapid, located a few miles downstream of Miles City at RM 174.2, consists of a long bedrock exposure and steep channel segment. The rapid has formed in sandstones of the Tullock Member of the Fort Union Formation (Vuke, et al, 2001). The steepest portion of the rapid extends between two mid channel bars, over a distance of approximately 0.6 miles (Figure 5-15). The LiDAR-derived water surface profile indicates that the rapid consists of a series of drops, each of which are several hundred feet long (Figure 5-16 and Figure 5-17).

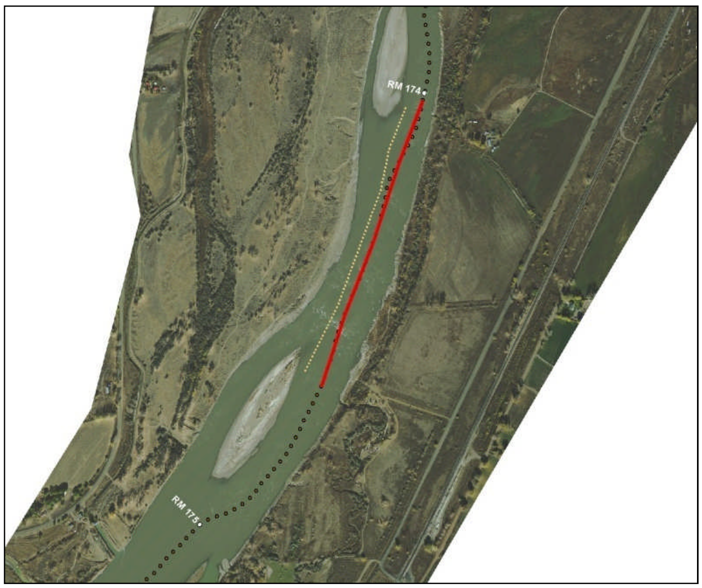


Figure 5-15 2007 Aerial Photograph of Matthews Rapid RM 174.2, Yellowstone River; red line refers to extent of slope anomaly, and centerline points are 100 ft increments.

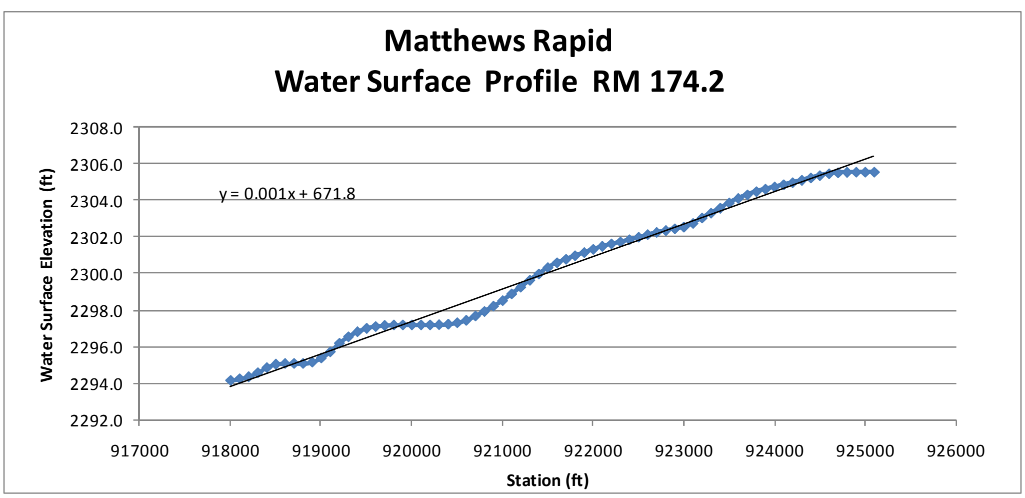


Figure 5-16 LiDAR-Derived Water Surface Profile, Matthews Rapid

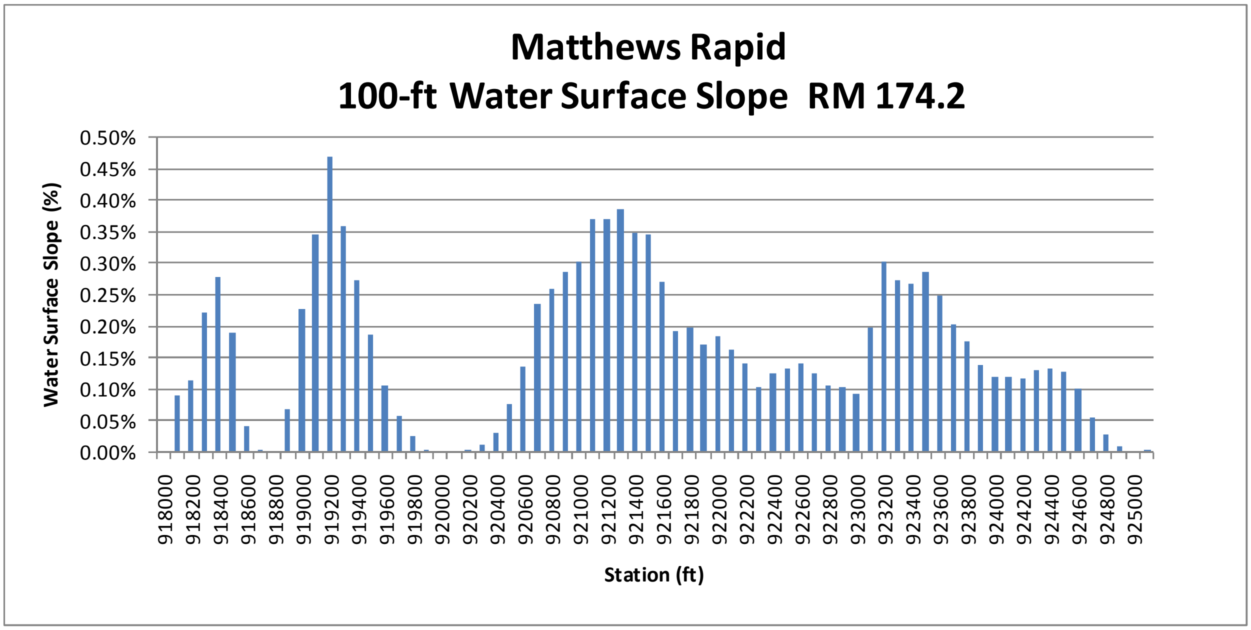


Figure 5-17 Water Surface Slope Calculated at 100-ft Increments, Matthews Rapid

The river bed at Matthews Rapid consists of a band of large, tabular, sandstone boulders spanning the entire river channel, but no discernable bedrock sills (Figure 5-18). The large boulders are interspersed by areas with gravel and large cobbles. Deeper flow pathways are present through the rapid and may provide migration routes for fish.

Figure 5-18 Matthews Rapid Looking North From the Right (southern) Bank

Adjacent to the steepest portion of Matthews Rapid, the right bankline is comprised of a coarse group of boulders that are continuous with the grade break in the channel (Figure 5-19). In order to estimate the size of the boulders in the rapid, a 92’ X 28’ cluster of boulders was flagged on the right riverbank adjacent to the steepest part of the rapid, and all boulders in the area were measured in terms of a-axis, b-axis, and c-axis lengths. A total of 144 clasts were measured and statistically summarized (Table 5-2). A box and whisker plot of the data shows that the range in 25th-75th percentile values (the “box”) is relatively small, but that maximum values are notably large, reaching 148 inches (12.3 feet) for the largest boulder measured (c-axis; Figure 5-20). A histogram showing results for all measurements less than 65 inches shows that the highest number of occurrences for the a-axes is 5 to 15 inches, for b-axes is 15-20 inches, and for C axes is 30-35 inches (Figure 5-21).

Figure 5-19 View From Right (southern) Bank Showing Steep Section of Matthews Rapid with Course Boulder Field in Foreground.

Table 5-2
Statistical Summary of Matthews Rapid Boulder Measurements

Statistic (inches)	A-Axis	B-Axis	C-Axis
Min	3	10	15
Median	11	22	33
Mean	12	26	39
Max	31	105	148
25th Percentile	9	16	25
75th Percentile	14	30	44
N	137	143	143
Standard Deviation	5	15	23

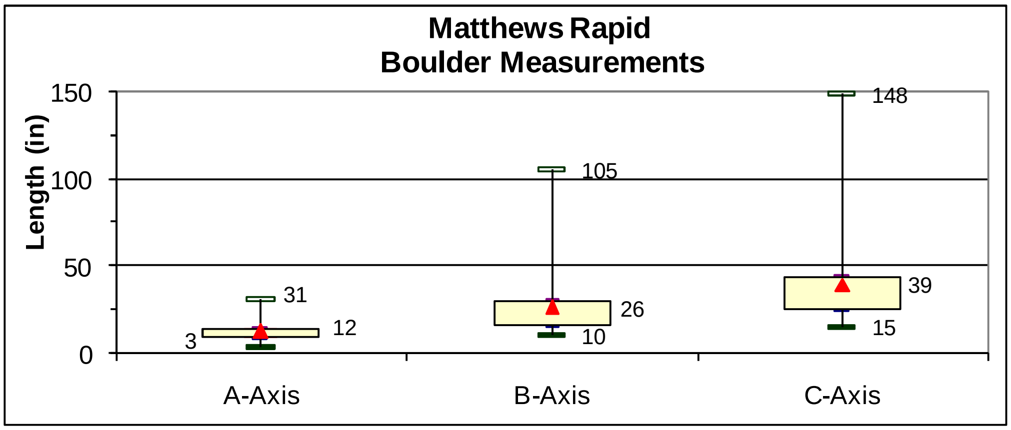


Figure 5-20 Box and Whisker Plot Showing Distribution of Boulder Measurements at Matthews Rapid; Minimum, Mean, and Max Values for Each Axis are Labeled

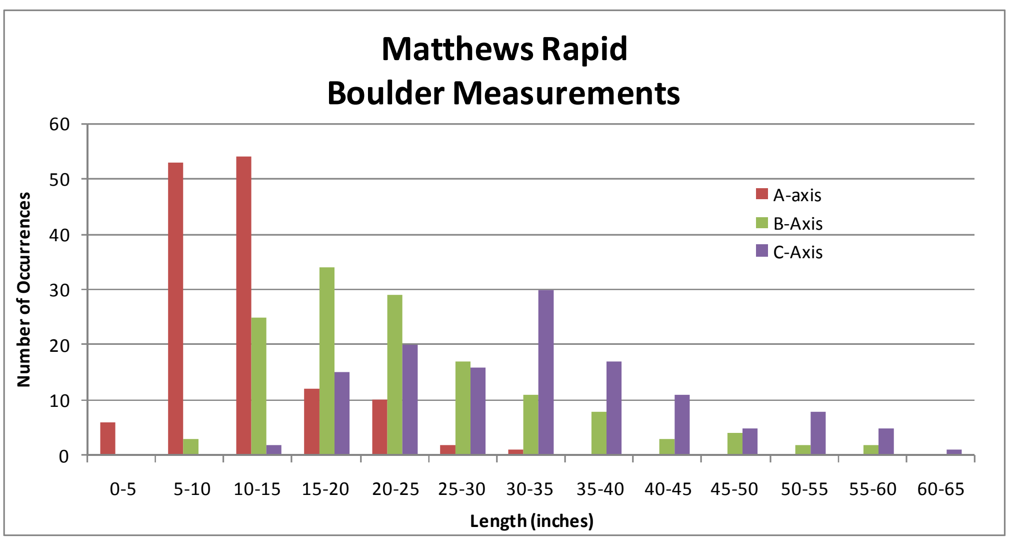


Figure 5-21 Histogram Showing Frequency of Number of Occurrences for Boulder Axis Measurements, Matthews Rapid

5.4.4.2.3.2 Wolf Rapid

Wolf Rapid is located at River Mile 146.0, approximately 3 miles downstream from the mouth of the Powder River (Figure 5-22). This rapid consists of a series of bedrock sills that extend across the channel on the apex of a large bendway. Similar to Matthews Rapid, the mapped geology on the base of the adjacent valley walls consists of interbedded sandstones, mudstones and limestone of the Tullock Member of the Fort Union Formation (Vuke and Colton, 2003). These hard sandstones appear to form the grade break at Wolf Rapid. At Wolf Rapid, the water surface slope is consistently steeper than 0.3% over several hundred feet of channel (Figure 5-23 and Figure 5-24).

Figure 5-22 2007 Aerial Photograph of Wolf Rapid, RM 146 Yellowstone River; red line refers to extent of slope anomaly and centerline points are 100ft increments.

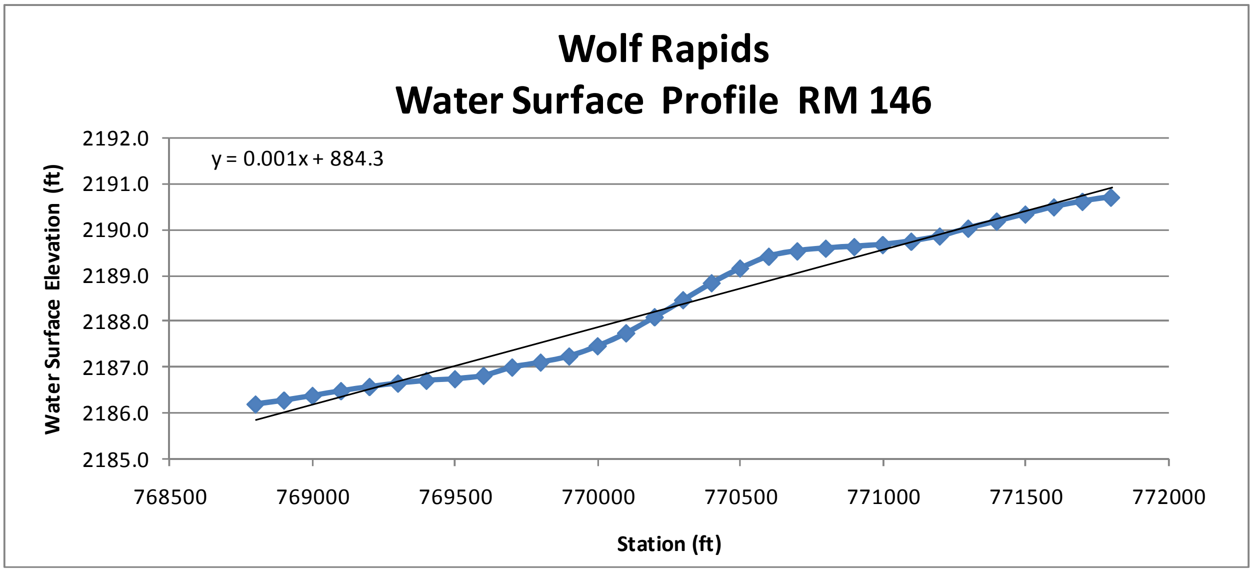


Figure 5-23 **LiDAR-Derived Water Surface Profile, Wolf Rapid**

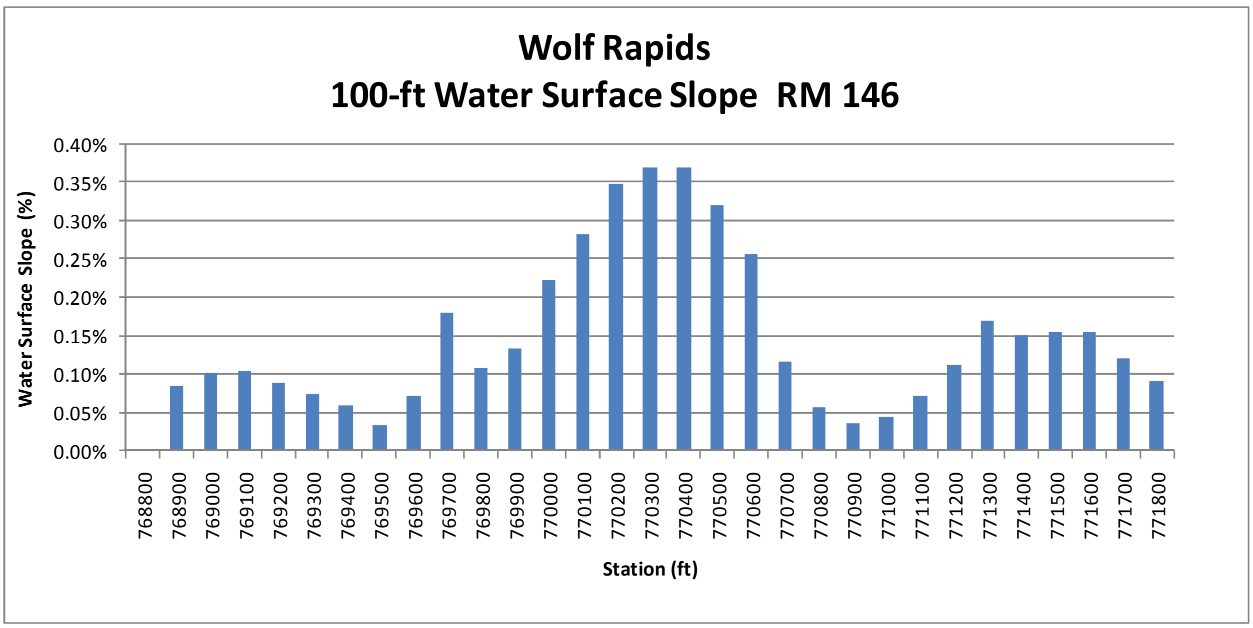


Figure 5-24 **Water Surface Slope Calculated at 100-ft Increments, Wolf Rapid**

The river bed at Wolf Rapid consists of a series of discontinuous sandstone steps created by bedrock sills (Figure 5-25). The rock sills cross the channel obliquely and slope downward from south to north. Consequently, flows on the north side of the rapid are deeper than on the south side. The sills are breached, creating chutes with well-defined, deeper flow pathways around and through the bedrock sills that might be used by sturgeon for passage. Flows over the tops of the rock sills exhibit supercritical flow conditions. The rock sills are interspersed by sections of river bed\ with more consistent grade and large cobble to large boulder substrates.

Figure 5-25 Wolf Rapid Looking Northwest From the Right (southeast) River Bank

5.4.4.2.4 Hydraulic Analysis of Matthews and Wolf Rapids

Based on the screening methodology described above, Matthews Rapid and Wolf Rapid were selected as potential design analogs for the rock ramp alternative. These features are characterized by water surface slopes that exceed 0.3% over several hundred feet of channel length. Cross sections (XS) and a stream bed profile at the two rapids were surveyed in September 2009 (Figure 5-26). Cross sections at each rapid were flagged to capture conditions through the slope anomalies. A total of five cross sections were surveyed at Matthews Rapid, and four at Wolf Rapids. These cross sections extend above and below the primary slope anomalies at each site.

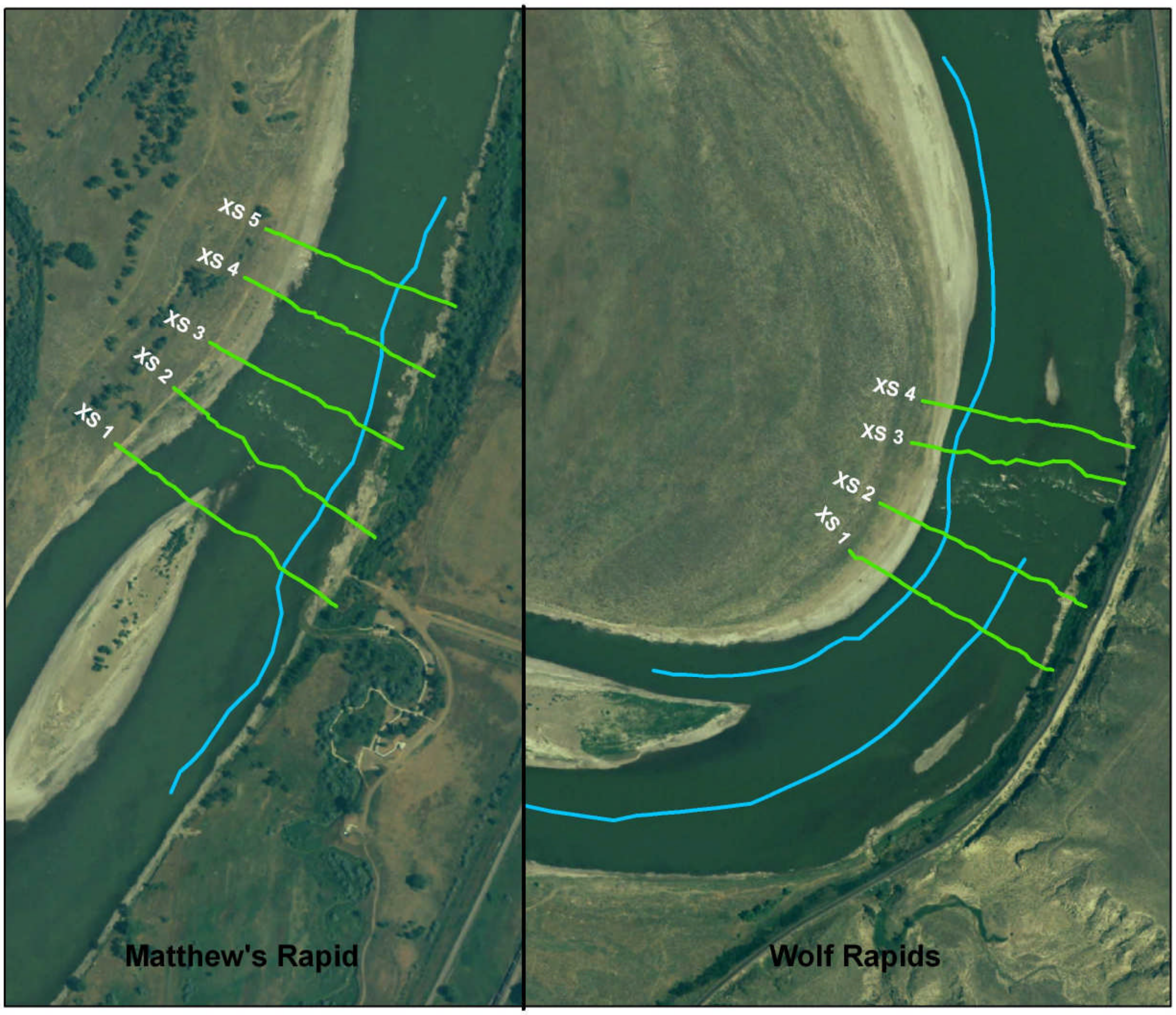


Figure 5-26 Cross-Sections (green lines) and Profiles (blue lines) Surveyed at Matthews Rapid and Wolf Rapid

For each suite of survey data, a simple, single station hydraulics package, WinXSPro, was used to evaluate the velocity and shear force at each cross-section for a range of discharges. WinXSPro calculates hydraulic parameters based on inputs of cross section geometry (surveyed station and elevation), channel slope, and Manning's n-value. The model can be run at a range of river stages (max water depth), to determine the hydraulic conditions (velocity, shear force) and discharge at that river stage.

The channel slope for each site was determined from the surveyed stream bed profile. In addition, the surveyed stream bed profile for each site was divided into segments based on visual interpretation of slope breaks. For Matthews Rapid, the profile was divided into two sections: upstream of XS 2 and downstream of XS 2 (see Figure 5-27). By applying a linear trendline to each section, we estimated a slope of 0.12% for the upstream section (profile points between XS 1 and 2) and 0.52% for the downstream section (profile points from XS 2 through 5). For Wolf Rapid, the profile was divided into three sections: upstream of XS 2, from XS 2 to XS 3, and downstream of XS 3 (see Figure 5-28). By applying a linear trendline to each section, we estimated a slope of 0.21% for the upstream section (XS 1), 0.53% for the middle section (XS 2 and 3), and 0.14% for the downstream section (XS 4). The maximum bed slopes measured from the survey are 0.52% at Matthews Rapid and 0.53% at Wolf Rapid. These bed slope values are substantially steeper than the water surface slopes measured by the LiDAR-generated water surface profile at both sites, which is on the order of 0.35% (Figure 5-16 and Figure 5-23).

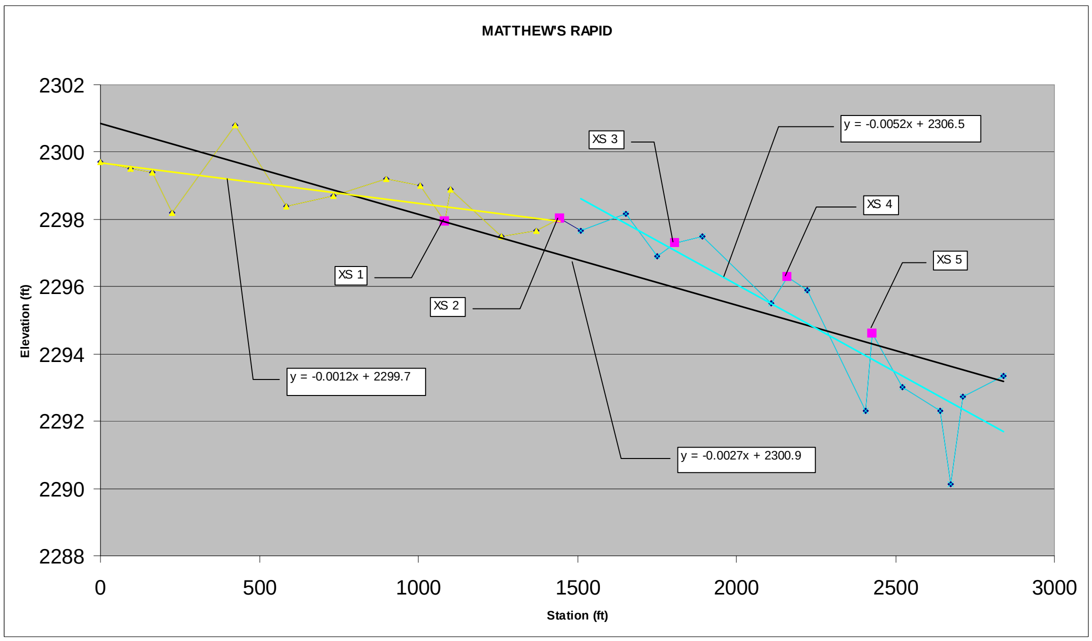


Figure 5-27 Surveyed Stream Bed Profile, Matthews Rapid, Broken Into Two Slope Segments

Manning's n-values for each cross section were calibrated based on two discharges, a low water event surveyed by DOWL HKM in September 2009, and a high water event surveyed by the USACE in June 2009. The low water discharge was measured at the USGS gage in Miles City: 7,490 cfs for Matthews Rapid and 7,510 cfs for Wolf Rapid. The high water event is determined from the velocity measurements on the days that data were collected by the USACE: 36,500 cfs for Matthews Rapid and 45,000 cfs for Wolf Rapid.

Using the edge of water points in each data set and the lowest cross-section point from the survey data, the maximum depth for each cross-section at each discharge was calculated. Each cross section was iteratively run in WinXSPro for a range of Manning's n-values until the resulting discharge at the observed maximum depth was equal to the measured discharge at the time of the survey. Using these calibrated high and low water event Manning's n-values, each cross-section was again run in WinXSPro for a range of stages based on a 0.1 ft increment of change.

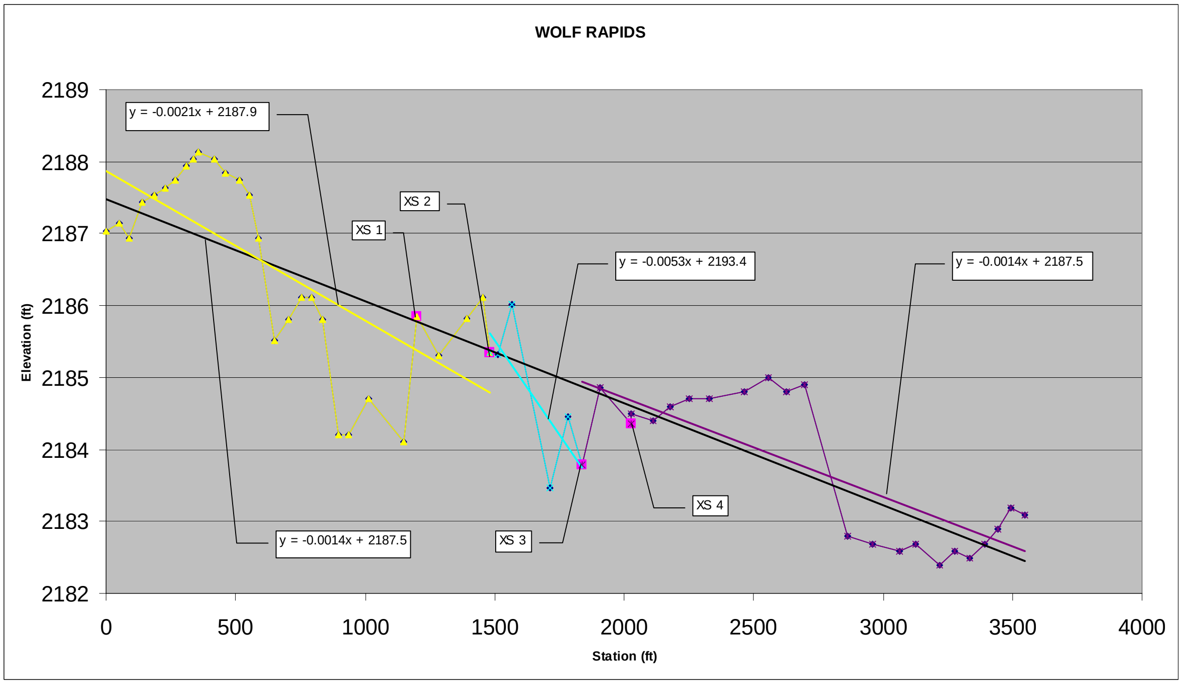


Figure 5-28 Surveyed Stream Bed Profile, Wolf Rapid, Broken Into Three Slope Segments

The river FLO-2D two-dimensional flow model was also calibrated to a flow of 7490 cfs at Matthews Rapid to verify its ability to accurately model these conditions (Figures 5-29 and 5-30).

5.4.5 Hydraulic Conditions at Natural Design Analogs During Known Passage Events

5.4.5.1 Discharge Range

Radio telemetry studies of sturgeon movements in the Yellowstone River have documented passage of 20 shovelnose sturgeon through Wolf Rapid at flows of at least 2,610 to 19,300 cfs (see Appendix A). At Matthews Rapid, 14 sturgeon were documented passing the feature at flows of at least 3,950 to 31,000 cfs (M. Jaeger, unpubl. data). Note that these flows represent the lowest discharges recorded during the time period when fish were captured below and then recaptured above the rapid. For example, fish number 480-66 was located on 6/3/2007 near river mile 70 when discharge was 19,300 cfs (Figure 5-31). This fish then swam approximately 75 miles upstream in 3 days and was recaptured just above Wolf Rapid near river mile 145 on 6/6/2007 when discharge was 37,700 cfs. Within this timeframe and range of

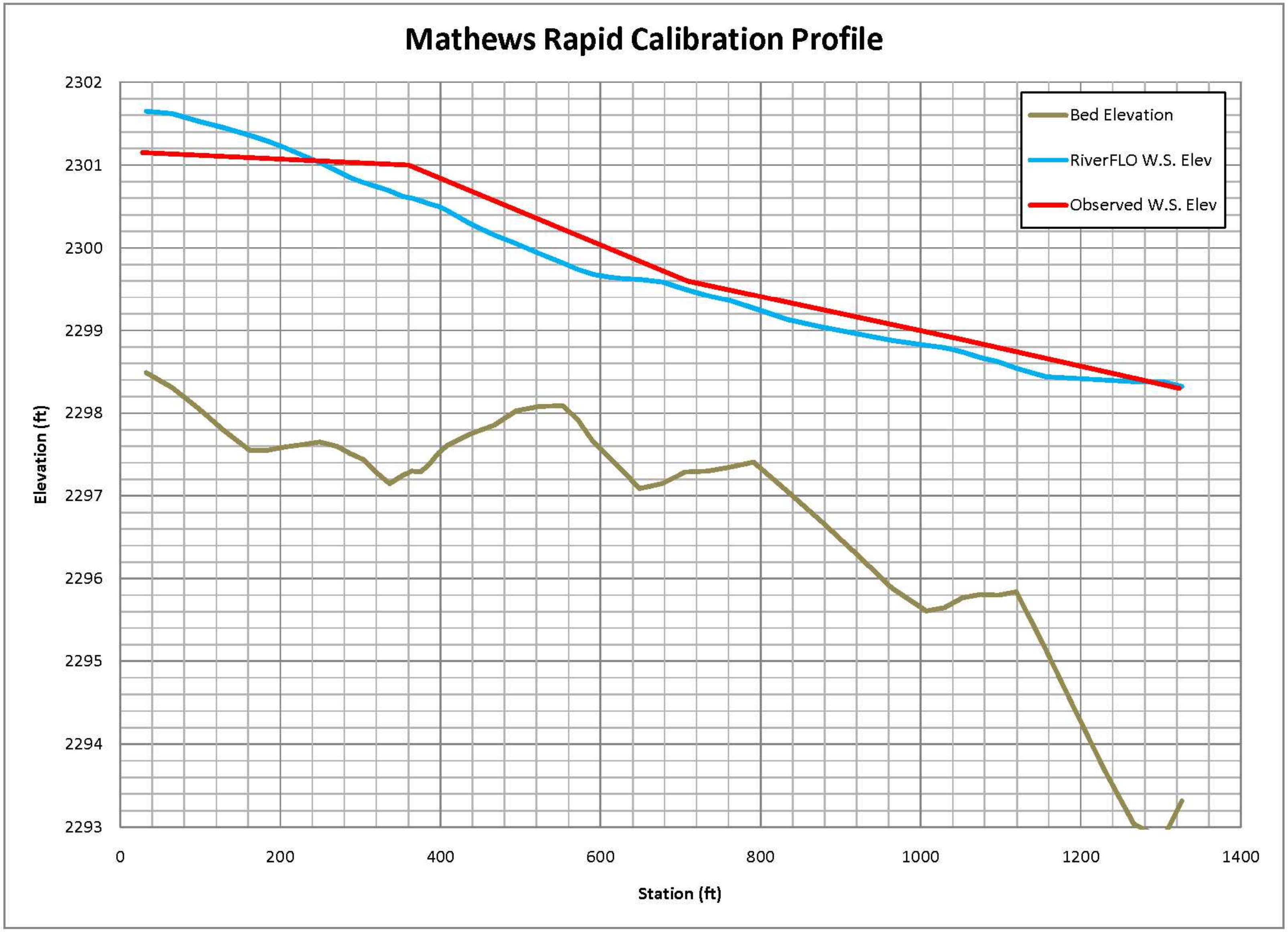


Figure 5-29 Matthews Rapid Calibration Profile

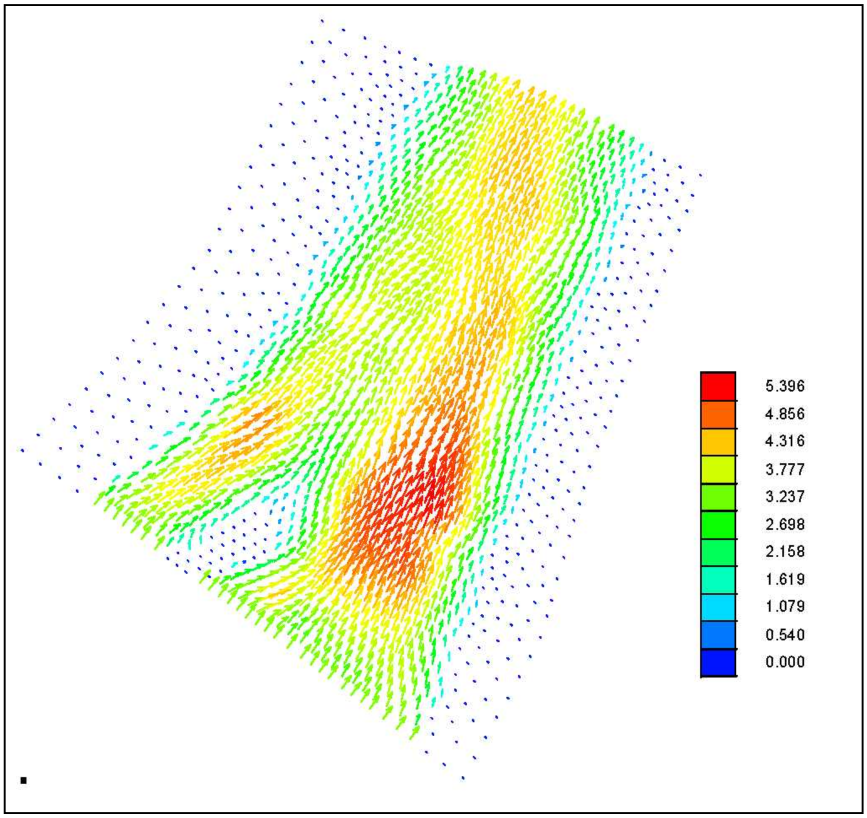


Figure 5-30 Matthews Rapid Velocity Profile (ft/s), Q = 7490 ft/s

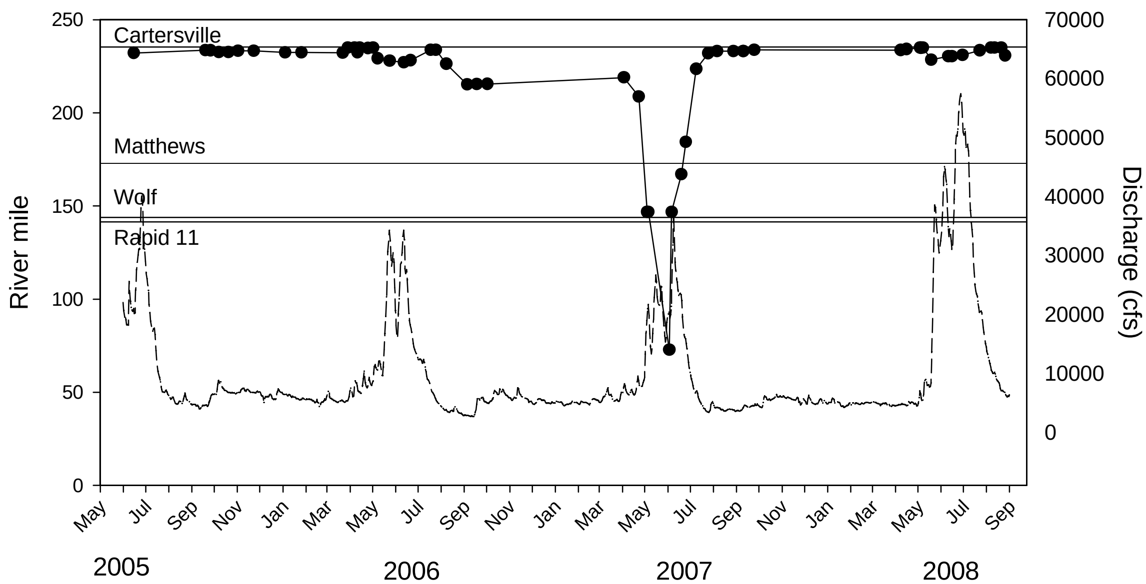


Figure 5-31 Movements of Shovelnose Sturgeon
Movements of shovelnose sturgeon number 480-66 in the Yellowstone River, 2005-2008. Sturgeon locations are indicated with black dots connected by a solid line; discharge at Miles City is displayed as a dashed line. Horizontal reference lines indicate the locations of Cartersville Dam and Matthews Rapid, Wolf Rapid, and Rapid 11 (M. Jaeger, unpubl. data).

flows it is uncertain exactly when this fish swam through Wolf Rapid. However, river flow rose consistently during this time period, so we know discharge had to be at least 19,300 cfs when 480-66 passed Wolf Rapid. Moreover, given the distance (nearly 75 miles) between the location where the fish was released and its recapture just above Wolf Rapid, it highly probable that the passage discharge was closer to the 37,700 cfs value recorded when the fish was recaptured. In the most extreme cases, therefore, we can conservatively conclude that one shovelnose sturgeon passed Wolf Rapid at a discharge of at least 19,300 cfs and two sturgeon passed Matthews Rapid at a discharge of at least 31,000 cfs. These extreme (but conservative) fish passage flows provide a glimpse of the potential swimming capability of shovelnose sturgeon in the wild.

5.4.5.2 Mean Velocity

The following tables (Table 5-3 and Table 5-4) show the results of WinXSPro runs for each cross-section at Wolf and Matthews rapids using discharges that bracket the extreme discharges where fish passage was documented.

Table 5-3
Hydraulic Analysis Results for Matthews Rapid
Bold values highlight the modeled discharge that is closest to the probable field discharge when two radio tagged shovelnose sturgeon passed this rapid.

XS	SLOPE (%)	N-VALUE	VELOCITY (ft/s)	SHEAR (psf)	DISCHARGE (cfs)	STAGE (ft)
1	0.12	0.030	5.30	0.40	29,232	8.9
		0.030	5.37	0.40	30,162	9.0
2	0.12	0.029	5.60	0.43	30,920	10.2
		0.063	5.68	0.43	31,867	10.3
3	0.52	**0.063**	**6.00**	**2.13**	**30,909**	**10.2**
		0.063	6.07	2.16	31,763	10.3
4	0.52	0.072	5.56	2.32	30,676	11.5
		0.071	5.61	2.34	31,373	11.6
5	0.52	0.080	5.19	2.45	30,633	12.2
		0.079	5.25	2.48	31,412	12.3

Table 5-4
Hydraulic Analysis Results for Wolf Rapid
Bold values highlight the modeled discharge that is closest to the probable field discharge when one radio tagged shovelnose sturgeon passed this rapid.

XS	SLOPE (%)	N-VALUE	VELOCITY (ft/s)	SHEAR (psf)	DISCHARGE (cfs)	STAGE (ft)
1	0.21	0.054	4.04	0.74	18,859	9.8
		0.054	4.10	0.76	19,477	9.9
2	0.53	0.087	4.13	2.00	18,805	9.4
		0.087	4.19	2.02	19,407	9.5
3	0.53	0.090	3.88	1.92	19,080	7.4
		0.090	3.91	1.95	19,566	7.5
4	0.14	**0.031**	**5.38**	**0.45**	**18,845**	**6.3**
		0.031	5.43	0.46	19,380	6.4

The model results indicate fish passed Matthews Rapid XS3 at average velocities at least as high as 6.00 ft/s, and Wolf Rapid XS4 at average velocities of at least 5.38 ft/s. As previously mentioned, actual passage may have occurred at higher discharges and velocities. It is important to note that these are averages of all velocities across the entire river cross-section and are not indicative of point velocities at specific locations within the cross-section. Point velocities may be significantly higher at some locations and significantly lower at others. Near the stream bed where sturgeon are typically found, flow velocities are often lower than average, especially when roughness is high.

The maximum recommended current velocity for sturgeon passage from laboratory flume studies is 4.0 ft/s (White and Mefford, 2002). However, field telemetry measurements for shovelnose and pallid sturgeon indicate sustained movement rates as high as 6.2 ft/s (6.8 km/h) and 8.6 ft/s (9.5 km/h), respectively (Bramblett 1996). These movement rates are based on the distance moved and the time elapsed between sequential locates of radio tagged fish within a time period <24 hours. It is important to note here that current velocity refers to the speed of flow past a stationary point; movement rate refers to the distance a fish moves in a given period of time regardless of current velocity; while swimming speed refers to the rate a fish travels through water. To illustrate, a fish that moves a distance of 3 feet in one second has a movement rate of 3 ft/s. If this fish is also swimming against a current velocity of 2 ft/s, it will have a net swimming speed of 5 ft/s. Similarly, a fish moving upstream at a rate of 4 ft/s in a current velocity of 0 ft/s will have a swimming speed of 4 ft/s. Movement rates are not the same as current velocity or swimming speed because the movement rates do not account for resting periods or any downstream movements the fish may have made between sequential locates. Moreover, movement rates assume a flow velocity of zero, so actual upstream swimming speed (rate of movement through water) in a riverine environment is actually higher than the movement rate. With these differences in mind, movement rates can provide a conservative surrogate estimate of the flow velocity fish may pass. Measured movement rates of 6.2 ft/s (Bramblett, 1996) support the WinXSPro results documenting shovelnose sturgeon pass Wolf and Matthews rapids when average flow velocities were at least 5.38 to 6.00 ft/s. We can conclude with some certainty, therefore, that, sturgeon are capable of passing natural rapids such as Wolf and Matthews Rapid at average flow velocities approaching 6.0 ft/s.

5.4.5.3 Roughness

As previously described, the channel bed at both reference rapids consisted of a complex mosaic of large boulders, bedrock sills, cobble, and gravel. This results in relatively high roughness (Manning's n) values, especially at low discharges. Indeed, low flow roughness at each rapid ranged from 0.026 to as high as 0.104 (Table 5-5). The boulders measured on the right bank adjacent to Matthews rapids indicate that discreet sandstone boulders larger than 4 feet in diameter are common. Within the 28-foot by 92-foot area within which individual rocks were measured, a total of 13 boulders had a b-axis in excess of 4 feet, and 33 boulders had a c-axis greater than 4 feet. These large boulders are indicative of the high bed roughness conditions at Matthews Rapid.

Table 5-5
Maximum Roughness Values for Similar Discharges at Matthews Rapid and Wolf Rapid

Matthews Rapid				Wolf Rapid			
XS	SLOPE (%)	N-VALUE	DISCHARGE (cfs)	XS	SLOPE (%)	N-VALUE	DISCHARGE (cfs)
1	0.12	0.033	3,563	1	0.21	0.065	2,382
2	0.12	0.033	3,521	2	0.53	0.111	2,321
3	0.52	0.076	3,593	3	0.53	0.078	2,362
4	0.52	0.084	3,518	4	0.14	0.026	2,283
5	0.52	0.104	3,637				
Average N for XS 3, 4, 5:		0.088		Average N for XS 2 & 3:		0.096	

Design of a rock ramp based on these natural rapid analogs will need to incorporate similarly high roughness values by emulating bed materials and spacing of the reference rapids.

5.4.5.4 Variability / Pathways

As previously discussed, the velocities presented in Table 5-6 and Table 5-7 are average velocities for the entire cross-section. In contrast, substantially slower and faster flows are likely to occur at specific locations throughout a cross-section for any given discharge. For example, velocities near the river bed and behind flow obstructions are probably slower than velocities at locations higher the water column or between obstructions. Sturgeon are considered to be benthic rheophiles (R. Bramblett, pers. comm.) and it is likely they take advantage of this flow heterogeneity by selecting passage pathways with the most favorable velocities and turbulence. As previously noted, White and Mefford (2002) reported adult pallid sturgeon in flume studies using cobble substrates with boulder weirs with flow velocities of 4 ft/s appeared to consistently search for and follow the same pathway and hydraulic conditions. Selection of passage pathways with favorable hydraulic conditions would allow sturgeon to conserve energy and to pass through rapids at higher discharges (higher average velocities) compared to a more random passage pathway.

Acoustic doppler current profiler (ADCP) surveys conducted by the Army Corps of Engineers (USACE) provide a means of mapping potential fish passage pathways through Wolf and Matthews rapids. These surveys collected a series of velocity measurements at closely spaced cross-section segments through each rapid. By drawing a line to connect the minimum velocity segment within each cross-section, a potential fish passage pathway may be prescribed. Figure 5-32 shows the location of the ADCP velocity measurement points and the probable minimum velocity passage pathways for each rapid. Table 5-6 and Table 5-7 provide the minimum, maximum, and average measured velocity and the flow depth at each ADCP cross-section through Wolf and Matthews rapids.

All but one of the potential flow path velocities in the ADCP study are higher than the 4.0 ft/s maximum flow velocity recommended by White and Mefford (2002). However, as previously noted, shovelnose sturgeon have been documented to move for sustained periods of time at rates of 6.2 ft/s. All of the potential flow path velocities measured by ADCP are below this value (Table 5-6 and Table 5-7), suggesting that at high discharges (45,000 for Wolf and 36,500 for Matthews rapid); sturgeon may still be able to find and use pathways through cross-section segment exhibiting lower velocities within their swimming capability.

Table 5-6
Water Velocities and Depths for Potential Fish Passage Pathways at Wolf Rapid
Minimum velocities were used to simulate potential fish passage pathways through the rapid.

Wolf Rapid
Discharge: 45,000 cfs

Station (ft)	Flow Path Velocity (ft/s)	Depth (ft)	Max. Velocity (ft/s)	Depth (ft)	Average Velocity (ft/s)	Location Relative to DOWL HKM Cross-section
0	4.72	15.44	7.92	11.76	6.00	Downstream of XS 4
196	5.84	11.84	8.03	10.16	5.90	Downstream of XS 4
418	5.69	11.79	7.77	10.28	5.77	Downstream of XS 4
628	4.23	17.28	7.96	10.15	6.25	Downstream of XS 4
814	5.82	8.89	7.61	10.73	5.44	Downstream of XS 4
926	4.58	9.66				XS 4
1082	5.09	11.07	7.89	10.20	5.92	XS 3
1261	4.98	11.07	8.95	4.94	5.73	Between XS 3 and 2
1445	5.98	9.15	7.99	8.03	6.46	Downstream of XS 2
1556	5.29	9.35				XS 2
1717	5.65	9.79	8.59	10.95	6.40	Between XS 2 and 1
1933	5.01	8.32	7.70	11.78	6.11	XS 1
2176	5.12	8.00	7.83	13.58	5.54	Upstream of XS 1
2420	5.26	7.86	7.48	10.28	5.82	Upstream of XS 1
2683	5.17	7.91	7.58	10.28	6.04	Upstream of XS 1
2850	5.26	8.01	7.46	8.95	5.60	Upstream of XS 1
3128	5.27	9.18	7.59	10.65	5.49	Upstream of XS 1

Table 5-7
Water Velocities and Depths for Potential Fish Passage Pathways at Matthews Rapid
Minimum velocities were used to simulate potential fish passage pathways through the rapid.

Matthews Rapid

Discharge: 36,500 cfs

Station (ft)	Flow Path Velocity (ft/s)	Depth (ft)	Max. Velocity (ft/s)	Depth (ft)	Avg. Velocity (ft/s)	Location Relative to DOWL HKM Cross-section
Right Passage Pathway						
0	4.50	9.84	7.92	9.84	5.59	Downstream of XS 5
240	3.69	14.17	8.34	13.64	5.75	Downstream of XS 5
447	5.08	14.61	7.91	7.18	5.76	Downstream of XS 5
656	5.09	11.33	7.44	9.88	5.70	XS 5
863	5.49	9.06	8.22	8.56	5.67	XS 4
996	5.29	7.93	-	-	-	Between XS 4 and 3
1094	5.68	7.89	7.93	7.43	5.93	Between XS 4 and 3
1313	5.43	9.51	7.50	7.33	5.27	XS 3
1522	4.64	8.98	8.64	9.31	6.36	Downstream of XS 2
1724	4.44	7.11	8.41	7.61	6.25	Upstream of XS 2
1929	4.77	6.23	8.08	8.16	5.95	XS 1
2163	4.67	6.09	8.06	7.32	6.01	Upstream of XS 1
2357	5.10	5.62	7.49	8.56	6.01	Upstream of XS 1
Left Passage Pathway						
0	5.01	11.35	7.92	9.84	5.59	Downstream of XS 5
178	5.34	12.93	8.34	13.64	5.75	Downstream of XS 5
394	5.51	13.1	7.91	7.18	5.76	Downstream of XS 5
599	5.39	12.29	7.44	9.88	5.70	XS 5
800	4.04	11.82	8.22	8.56	5.67	XS 4
1021	4.98	9.47	7.93	7.43	5.93	Between XS 4 and 3
1211	4.08	10.33	7.50	7.33	5.27	XS 3
1423	4.25	6.49	8.64	9.31	6.36	Downstream of XS 2
1624	3.89	7.24	8.41	7.61	6.25	Upstream of XS 2

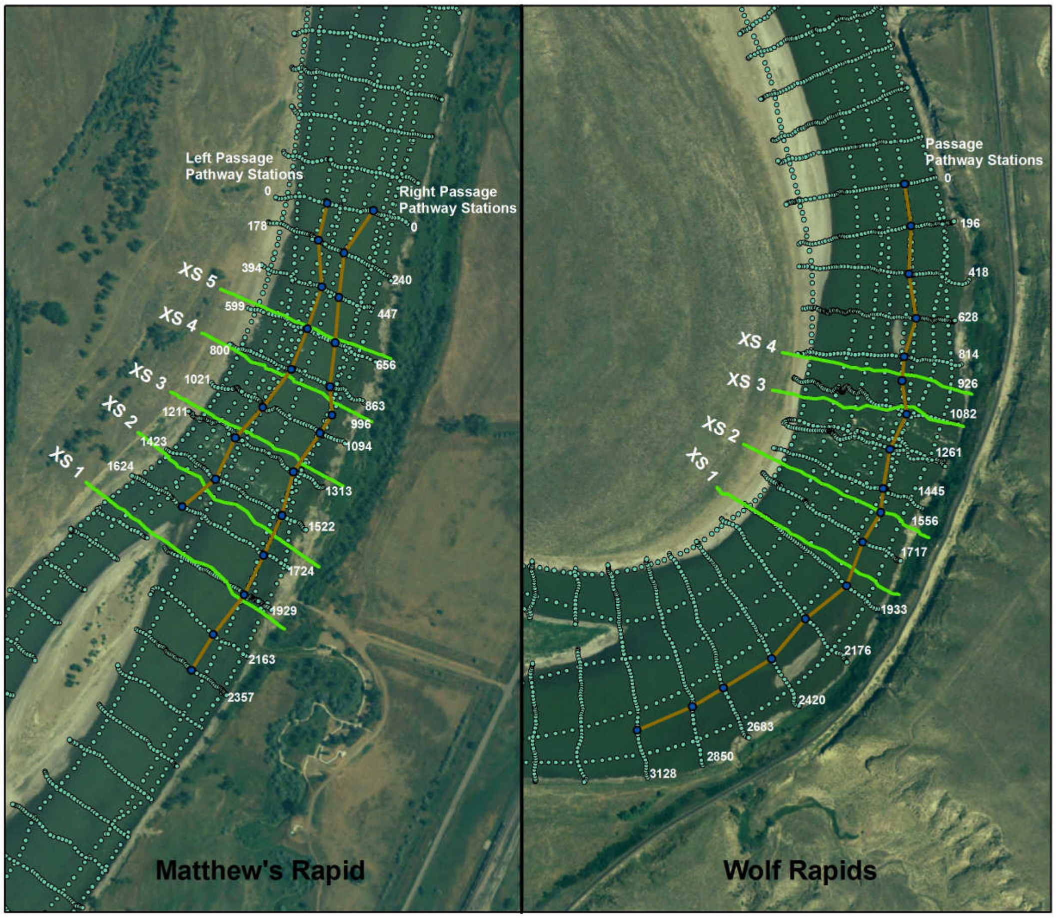


Figure 5-32 ADCP velocity measurement points (light green points) and potential fish passage pathways (brown lines) through Matthews Rapid and Wolf Rapids.

5.4.5.5 Slope and Slope Length

The reference riffles (Matthews Rapid and Wolf Rapid) are characterized by surveyed stream bed slopes ranging between 0.12% and 0.53%. For Matthews Rapid, the slope was divided into two sections: 0.12% for approximately 1445 ft and 0.52% for approximately 1395 ft (see Figure 5-27). For Wolf Rapid, the slope was divided into three sections: 0.21% for approximately 1482 ft, 0.53% for approximately 355 ft, and 0.14% for approximately 1710 ft (see Figure 5-28). These data demonstrate that shovelnose sturgeon are capable of passing bed slopes of 0.53% that are sustained over distances as high as 1,482 feet if channel.

5.4.6 Fish Passage Design Criteria

The preceding data and analyses are summarized here to create a suite of design criteria for sturgeon passage at Cartersville Dam. These criteria are based primarily on surveys and analyses of Wolf and Matthews Rapid on the Yellowstone River, but also incorporate data from published and unpublished literature. When applied to the design of a rock ramp fish passage structure, these criteria will help to ensure the design replicates the conditions found in two rapids that shovelnose sturgeon have been documented to pass.

5.4.6.1 Mean Velocity

Mean cross-section velocity at Matthews Rapid was as high as 6.0 ft/s during discharges when sturgeon were known to pass (Table 5-7). Mean velocity of the proposed rock ramp should, therefore, not exceed 6.0 ft/s. Note, however, that fish are likely to pass at higher flows and velocities.

5.4.6.2 Roughness

The reference rapids had highly variable bed substrates that resulted in high roughness values. The proposed rock ramp surface should include a complex mosaic of large boulders, cobble, and gravel arranged to create roughness values greater than 0.07. The average roughness values for Matthews Rapid and Wolf Rapid were 0.054 and 0.070, respectively (Table 5-5). The mosaic of sandstone boulders measured at Matthews Rapid, which reach several feet in diameter, can be used to help define appropriate gradations and boulder shapes. The maximum side length of these boulders (c-axis) ranged from approximately 2 feet to 12 feet. In a 2576 square foot area, a total of 33 boulders had a C-axis length in excess of 4 feet.

5.4.6.3 Variability / Pathways

The arrangement of bed materials in the proposed rock ramp should create variable velocity pathways that fish may use to navigate through rapids at high flows. Wolf Rapid includes intact bedrock sills that would be difficult to construct and maintain. Consequently, we recommend using the size and distribution of bed materials in Matthews Rapid to design the rock ramp at Cartersville Dam.

5.4.6.4 Maximum Bed Slope

The steepest sections of Matthews and Wolf rapids have bed slopes of approximately 0.5%. This includes the lower section of Matthews Rapid (Figure 5-27) and the middle section of Wolf Rapid (Figure 5-28). Therefore, we recommend the slope of a rock ramp at Cartersville be < 0.5%.

5.4.6.5 Length of Maximum Slope

Maximum slopes at Matthews Rapid were sustained for distances of up to 1,482 feet. It is not known whether sturgeon can pass steeper or longer rapids, so the maximum length of 0.5% slope should not exceed 1,400 feet.

5.4.6.6 Design Criteria

The design criteria based on analysis of Matthews Rapid and Wolf Rapid are provided in Table 5-8.

Table 5-8
Rock Ramp Design Criteria

Criterion	Value
Maximum Slope	< 0.5%
Maximum Slope Length	< 1,400 ft
Mean Velocity	< 6 ft/s
Roughness	> 0.07

5.4.7 Biological Review Team Scoring Criteria

In 2006, the US Fish and Wildlife Service assembled a Biological Review Team (BRT) of pallid sturgeon experts to review preliminary fish passage design options for the Intake Dam (Jordan 2006). The BRT developed a series of scoring criteria to evaluate the relative merits of various pallid sturgeon passage design alternatives under consideration for the irrigation dam at Intake, Montana. While these criteria may not be directly applicable to passage of shovelnose sturgeon at Cartersville Dam, they are instructive as the more common shovelnose sturgeon are sometimes used as surrogates for understanding rare pallid sturgeon (Bramblett and White 2001; Adams et al. 2003). The scoring criteria included the following parameters:

1. Percentage of time the alternative provides flow velocities that are passable for juvenile and adult pallid sturgeon.
2. Percentage of the structure's surface area that meets the velocity criteria for passage of juvenile and adult pallid sturgeon.
3. Depth of structure meeting minimum depth requirements as well as velocity specifications (≤1-2 ft/s for juvenile and ≤4 ft/s for adults).
4. Presence of vertical sills greater than 0.3m either designed or likely to occur within alternative.
5. Ability to tune or modify structure to improve passage if needed.
6. Degree of uncertainty associated with the alternative.

For conceptual design of a fish passage solution for Cartersville Dam, a geomorphic/hydraulic design approach has been adopted that emulates as closely as possible the hydraulic conditions within natural rapids sturgeon routinely pass. These hydraulic conditions are determined by discharge, slope, depth, velocity, roughness, and the distribution of bed materials within the channel. To guide the design of a fish passage structure at Cartersville, we have developed a series of design criteria (Table 5-8) that capture many of the important hydraulic characteristics of natural rapids in the Yellowstone River. For clarity, we use the term "design criteria" to refer to the criteria developed from natural riffles, and the term "scoring criteria" to refer to the criteria developed by the BRT.

The following is a discussion of the BRT scoring criteria and how they compare to the geomorphic/hydraulic design criteria developed during this study.

Criterion 1 – Percentage of time the alternative provides flow velocities that are passable for juvenile and adult pallid sturgeon. This criterion is to be scored as follows:

Juveniles (Alternative provides ≤1-2 ft/sec velocities during April – September)

% of period criteria are met	Score
100	100
75	75
50	50
25	25
0	0

Adults (Alternative provides ≤4 ft/sec velocities during April – June)

% of period criteria are met	Score
100	100
99-75	50
<75	0

Discussion – It is assumed the BRT's velocity scoring criteria (≤1-2 ft/sec for juvenile sturgeon and < 4 ft/s for adult sturgeon) refer to average flow velocity through the water column in keeping with the results reported by White and Mefford (2002). In contrast, the proposed rock ramp design criterion of <6.0 ft/s for Cartersville refers to average velocity across the entire river cross-section. Please note these criteria (both design and scoring) may be difficult to evaluate in a meaningful way as velocity near the bed may be the most critical measure for sturgeon passage, and average water column or cross-section velocity does not indicate near-bed velocity conditions. Nevertheless, we are confident the < 6.0 ft/s design criterion is reasonable based on field measurements, which are typically more reliable than laboratory studies.

Criterion 2 – Percentage the structure's surface area that meets the velocity scoring criteria for passage of juvenile and adult pallid sturgeon. This criterion is to be scored as follows:

Juveniles (Alternative provides ≤1-2 ft/sec velocities during April – September)

% of structure meeting criteria	Score
≥ 30	100
30-20	50
< 20	0

Adults (Alternative provides ≤4 ft/sec velocities during April – June)

% of structure meeting criteria	Score
≥ 50	100
< 50	0

Discussion – This scoring criterion is intended to ensure that a relatively large percentage of the surface area of the proposed alternative meets the velocities presented in scoring criterion 1. However, it is uncertain what percentage of the surface area of Matthews and Wolf Rapids actually meets the scoring criterion of ≤1-2 ft/sec for juvenile sturgeon and ≤4 ft/s for adult sturgeon, especially at higher flows when sturgeon often move upstream. It is important to note that if less than 50% of Matthews or Wolf Rapids meets the ≤4 ft/s scoring criterion at any time during April to June, then these natural riffles would receive a score of zero for adult sturgeon passage even though they are known to pass adult fish at relatively high discharges within this time period. Consequently, this scoring criterion may be unreasonably conservative. A comparable design criterion was not developed for Cartersville Dam. Further evaluation of this scoring criterion is recommended based on 2-dimensional modeling of Matthews and Wolf Rapids at a range of flows to determine the percentage of the surface area of these natural rapids that have flow velocities meeting scoring criteria 1.

Criterion 3 – Depth of structure meeting minimum depth requirements as well as velocity specifications (≤1-2 ft/sec for juvenile and ≤4 ft/sec for adults). This criterion is to be scored as follows:

Juveniles (Alternative provides ≤1-2 ft/sec velocities at the specified depths)

Depth	Score
> 1 m	100
.99-0.5 m	50
< 0.5 m	0

Adults (Alternative provides ≤4 ft/sec velocities at the specified depths)

Depth	Score
> 1 m	100
.99-0.5 m	50
< 0.5 m	0

Discussion – It is assumed this scoring criterion is intended to ensure that a passage alternative has depths > 1 m while also meeting the preceding scoring criteria 1 and 2. To receive a score of 100 for adult sturgeon, this would mean >50% of the structure (scoring criterion 2) would have depths >1 m (scoring criterion 3) and velocities ≤4 ft/s from April through September (scoring criterion 1).

In the natural rapids surveyed on the Yellowstone River in September 2009, all cross-sections had some areas with depths exceeding 1 m. We have elected to use the higher gradient cross-sections 2, 3, and 4 at Matthews Rapid and cross-sections 2 and 4 at Wolf Rapid for the design of a rock ramp at Cartersville (Table 5-9). When considering depths averaged across the entire cross-section, only 1 of three cross-sections at Matthews Rapid exceeded an average depth of 1 m, while both of the cross-sections selected at Wolf Rapid had average depths >1 m. Moreover, the percentage of survey points that exceeded 1 m in depth was <50% for 2 of 3 cross-sections at Matthews Rapid and for 1 of 2 cross-sections at Wolf Rapid. This would suggest that the natural riffles used to develop design criteria for Cartersville Dam would receive low scores under the BRT's recommended depth scoring criteria. Consequently, the BRT's scoring criteria may be conservative with respect to replicating hydraulic conditions in natural rapids in the Yellowstone River.

Table 5-9
Average Depths and Percentage of All Depths Exceeding 1 m for Cross-Sections Surveyed at Matthews and Wolf Rapids on the Yellowstone River in September 2009

Matthews Rapid				Wolf Rapid			
XS	**Avg. Depth (m)**	**Avg. Depth (ft)**	**% Depth >1m**	**XS**	**Avg. Depth (m)**	**Avg. Depth (ft)**	**% Depth >1m**
2	**2.64**	**0.80**	**33%**	2	**3.68**	**1.12**	**52%**
3	**2.87**	**0.88**	**35%**	3	**3.34**	**1.02**	**42%**
4	**3.55**	**1.08**	**55%**				

Criterion 4 – Presence of vertical sills greater than 0.3m either designed or likely to occur within alternative. This criterion is to be scored as follows:

Vertical sill > 0.3 m	Score
No	100
Yes	0

Discussion – It is proposed to model the size and distribution of bed materials for the Cartersville rock ramp after Matthews Rapid, which contains large sandstone boulders and bedrock fragments, but no discernable rock sills. Consequently, the design for Cartersville Dam should meet this criterion. It is instructive to note, however, that Wolf Rapid contains numerous, extensive rock sills greater than 0.3 m high, yet this rapid is readily passable to shovelnose sturgeon.

Criterion 5 – Ability to tune or modify structure to improve passage if needed. This criterion is to be scored as follows:

Ability to Modify Structure	Score
Easy to modify structure	100
Moderately difficult to modify	75
Very difficult to modify	50

Discussion – Following our adaptive management philosophy, it is agreed any designs should provide the ability to tune or modify the structure to improve passage.

Criterion 6 – Degree of uncertainty associated with the alternative. This criterion is to be scored as follows:

Level of uncertainty	Score
Low	100
Med	50
High	0

Discussion – The empirical, geomorphic approach to designing fish passage at Cartersville Dam is founded upon replicating natural conditions that shovelnose sturgeon have been documented to successfully pass. As a result, the passage design criteria for Cartersville Dam have a very low level of uncertainty compared to alternative design criteria based solely on theoretical, or purely modeled criteria.

5.4.8 Plans

Based on results of the February 2009 study and subsequent meetings two alternative plans were selected for further evaluation:

- Alternative 1: Rock ramp
- Alternative 2: Inflatable bladder

5.4.8.1 Alternative 1: Rock Ramp

5.4.8.1.1 Introduction

The rock ramp alternative consists primarily of a rock ramp in the north channel of the Yellowstone River below the diversion dam, a berm from the south abutment of the diversion dam to the south edge of the north channel (north side of island) to control the split of river flows to the north and south channel, and bank protection/apron downstream of the rock ramp.

The rock ramp will be constructed of a four-foot thick layer of 1-4 foot riprap. The rock ramp begins at the crest elevation of the existing dam and terminates downstream where the top of the rock ramp intersect the existing river bed. Natural channel material will be excavated to a depth of four feet where necessary to install the riprap to the estimated depth of scour. The excavated bed material will be used to fill the scour hole at the toe of the existing dam, with any remaining material used to fill voids within the riprap rock ramp. At the downstream terminus of the rock ramp, a four-foot apron of riprap will be placed from bank to bank and will extend a distance of one-half the channel width downstream of the toe of the rock ramp to prevent erosion. The channel bottom will be excavated four feet to place the riprap, whereas on the banks, the riprap will be placed over the existing surface.

The south channel will be left intact based on the desires of the Cartersville Irrigation District and the community.

Criteria for development of the rock ramp alternative include design criteria developed in this study, input from the Cartersville Irrigation District and local community, and other rock ramp projects under design or already constructed.

5.4.8.1.2 Hydraulic Modeling

The rock ramp alternative is evaluated for three options each utilizing a different bed slope configuration.

5.4.8.1.2.1 Option 1: Slope 0.5% / 0.2% / 0.5%

The design criteria call for a maximum slope of 0.5% no longer than 1400 feet. This option utilizes a slope of 0.5% for 600 feet, a flatter slope of 0.02 for 200 feet, and another slope of 0.5% for 600 feet (Figure 5-33).

The design criteria also specify a maximum mean channel velocity of 6.0 ft/s. The proposed rock ramp was modeled with both the USACE HEC-RAS model and River FLO-2D, a two-dimensional model.

Results from HEC-RAS for a flow of 6500 cfs indicate a mean channel velocity of the rock ramp of less than 6 ft/s using a design “Manning’s n” of 0.070.

River FLO-2D was used to model three flow rates. The first is a flow of 2700 cfs which is the 99 percent exceedance flow at the USGS Forsyth gage. This means the flow at the gage equals or exceeds 2700 cfs 99 percent of the time. The second flow is 6500 cfs which was the flow at the time of the field survey. The third is a flow of 48,800 cfs which is equaled or exceeded one percent of the time.

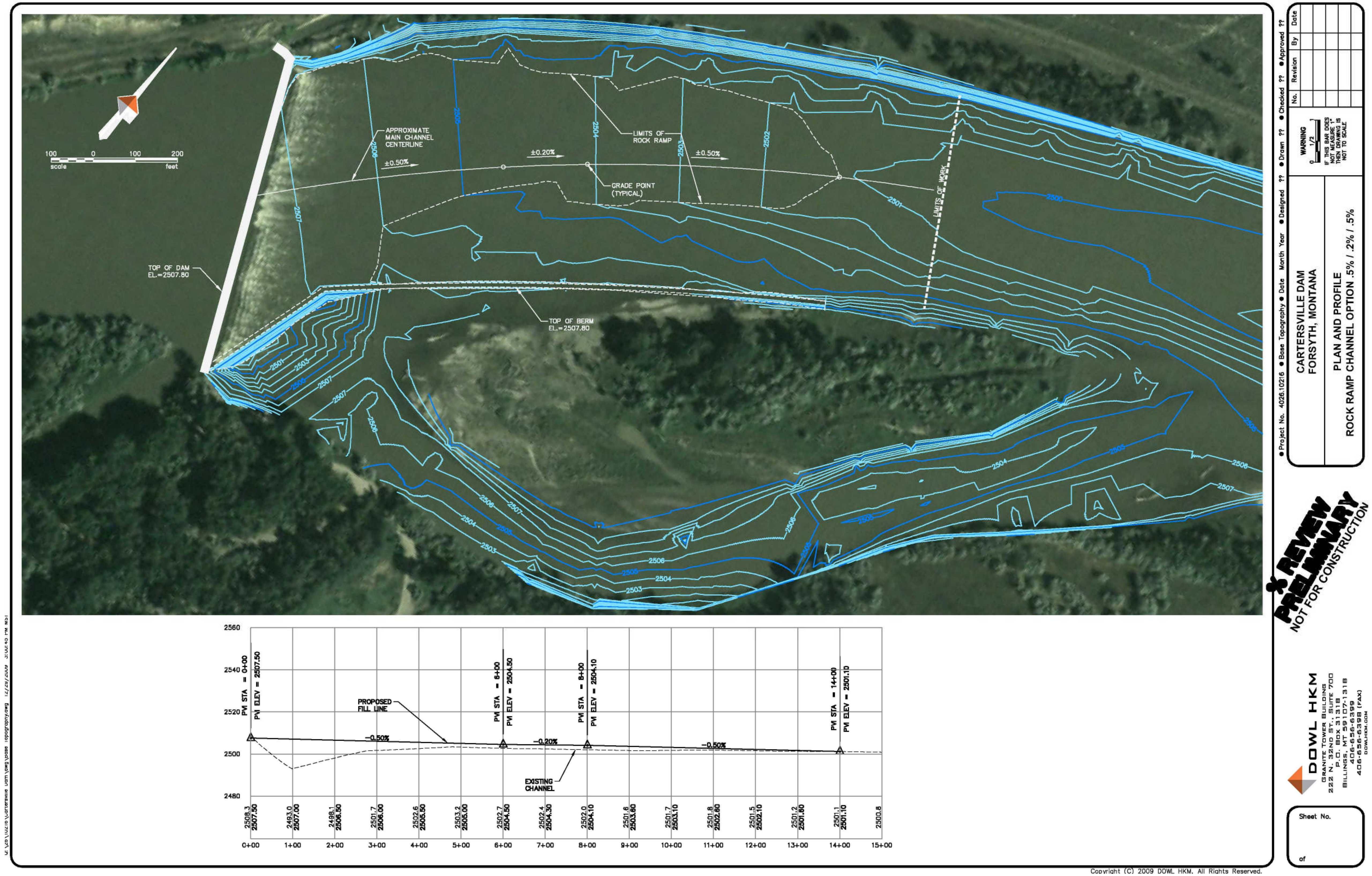


Figure 5-33 Rock Ramp, Slope 0.5% / 0.2% /0.5%, Option 1

For flows of 2700 cfs and 6500 cfs, mean water column velocities at all discrete points on the rock ramp are less than 5 ft/s (Figures 5-34, 5-35). For a flow of 48,800 cfs, the mean water column velocity on the rock ramp reaches a maximum of 6.3 ft/s (Figure 5-36). Water depths are shown on Figures 5-37, 5-38, and 5-39.

Water surface profiles for all three flows are shown on Figure 5-40. A cross section through the north and south channel is shown in Figure 5-41.

The division of flows between the north and south channels is shown in Table 5-10. Approximately 80 percent of the flow over the dam goes to the north channel under all flows. This should be adequate to maintain attraction flows that favor the north channel and the rock ramp structure while maintaining some flows in the south channel for recreational use.

Table 5-10
Rock Ramp Division of Flows

	Q = 48800	Q = 6500	Q = 2700
North Channel Totals:	38883.2	5178.1	2018.3
North Channel Percent of Total:	79.8%	80.9%	79.4%
South Channel Totals:	9872.6	1219.0	525.1
South Channel Percent of Total:	20.2%	19.1%	20.6%
Total Flow:	48755.8	6397.1	2543.4

5.4.8.1.2.2 Option 2: Slope 0.5%

This option is similar to Option 1 but utilizes a constant slope of 0.5% (Figure 5-42) by eliminating the 200-ft long section of 0.2% slope. A rock apron of ½ channel width is included. This option was also modeled and satisfies the geomorphic/hydraulic design criteria except for exceeding 6 ft/s slightly at a flow of 48,800 cfs. See Figures 5-43 through 5-50.

5.4.8.1.2.3 Option 3: Slope 0.5% / 1.27%

This option starts with a slope of 0.5% for a distance required to maintain subcritical flow over the full range of flows and then steepens at the downstream end to meet the streambed. Modeling indicated the 0.5% grade must continue for approximately 270 feet downstream from the dam to maintain subcritical flow. A slope of 1.27% was then utilized to meet a high point on the river bed downstream, thereby significantly reducing the amount of rock required (Figure 5-51). A rock apron of ½ channel width is included. This option satisfies all of the design criteria except for slope at the downstream end of the rock ramp. However, if the steeper slope section proves to be an impediment to sturgeon passage, the structure could be easily modified by adding more rock to the downstream end to emulate Option 2, which has a constant 0.5% slope. The Option 2 concept is also being considered by the USACE for Intake Dam.

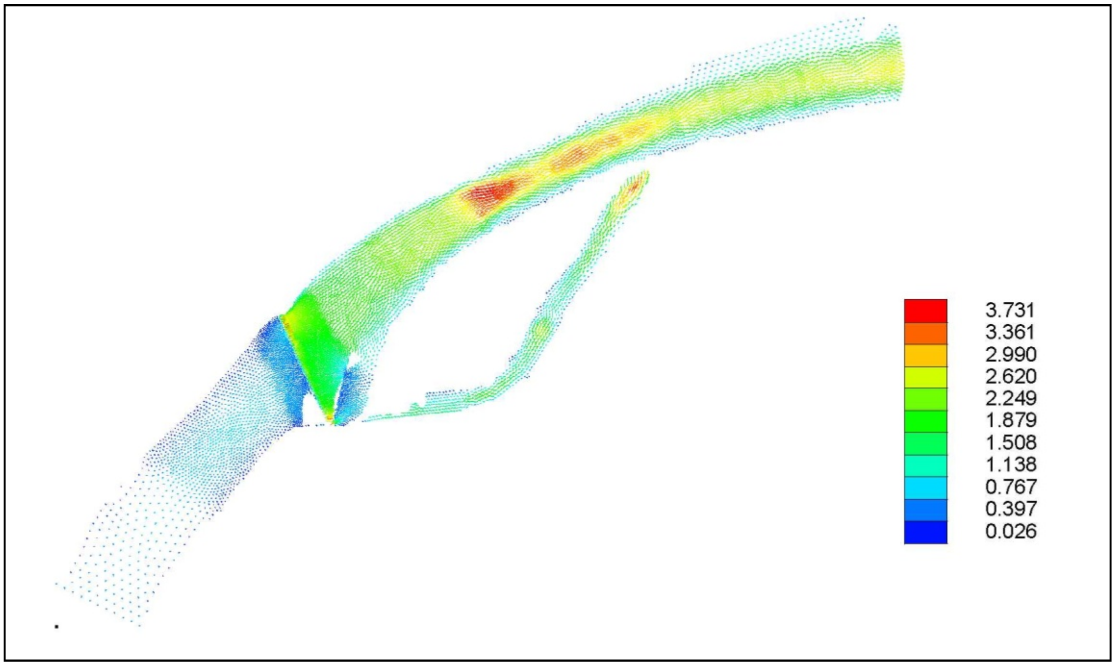


Figure 5-34 Mean Column Velocities (ft/s), Q = 2700 cfs, Option 1

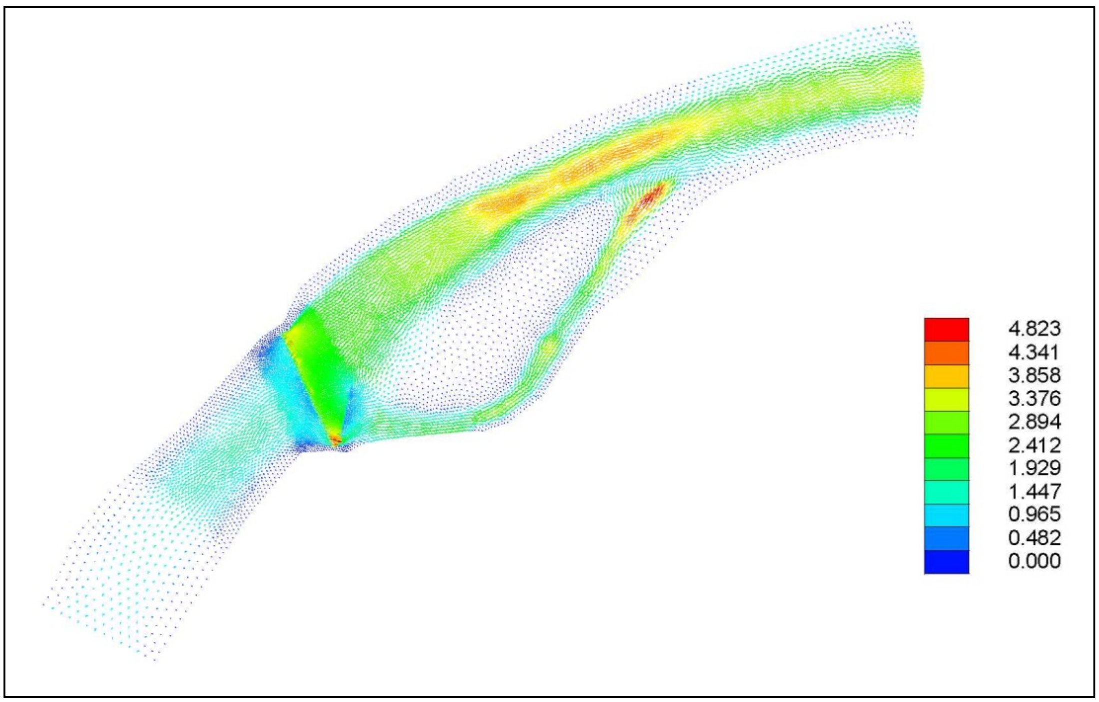


Figure 5-35 Mean Column Velocities (ft/s), Q = 6500 cfs, Option 1

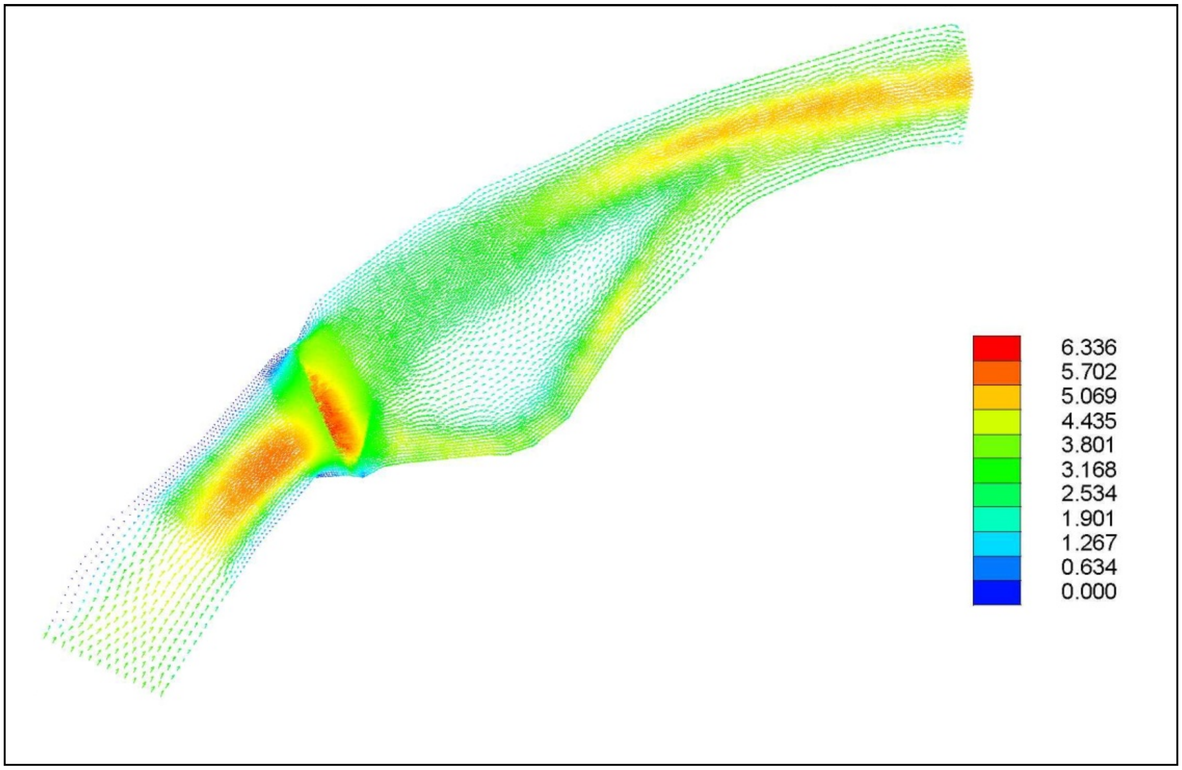


Figure 5-36 Mean Column Velocities (ft/s), Q = 48,800 cfs, Option 1

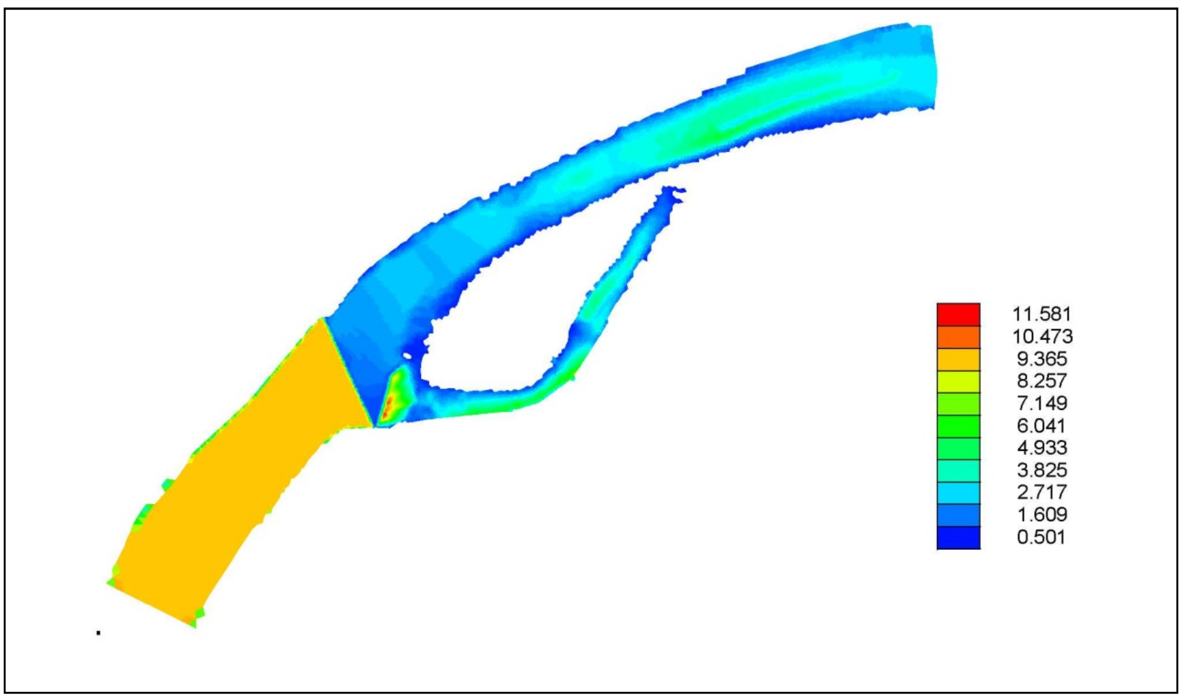


Figure 5-37 Water Depth (ft), Q = 2700 cfs, Option 1

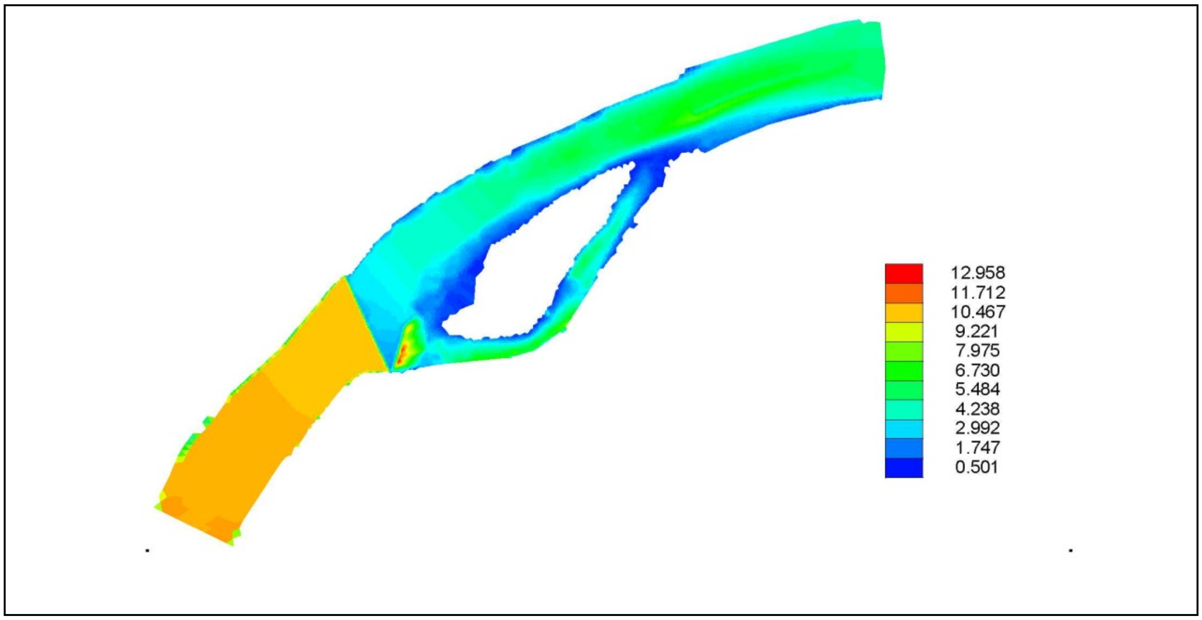


**Figure 5-38	Water Depth (ft), Q = 6500 cfs, Option 1**

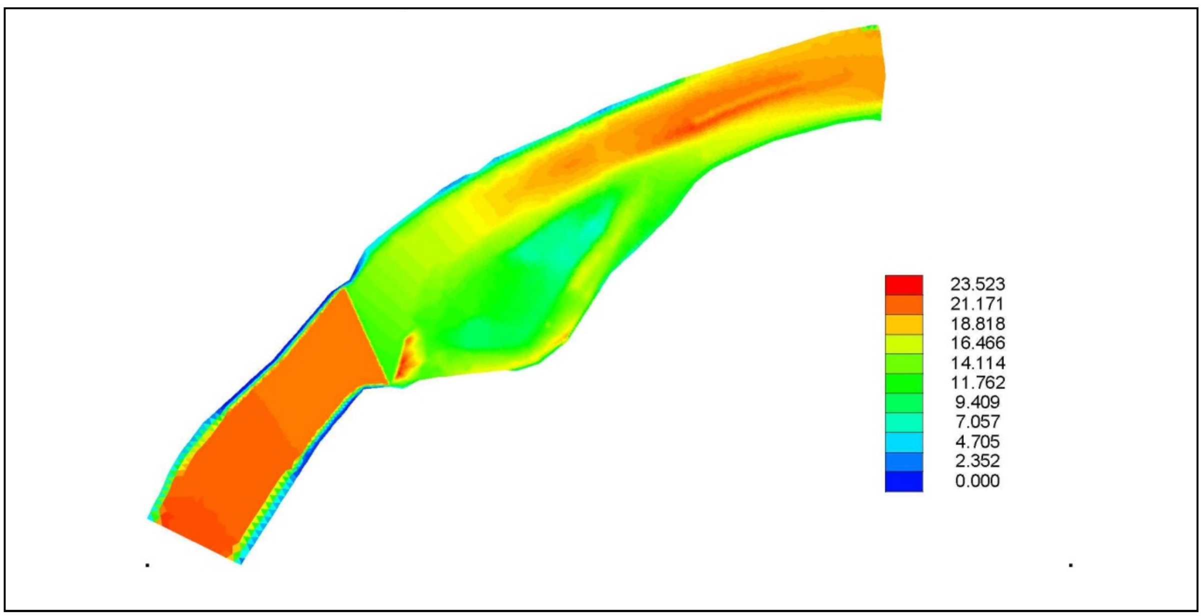


**Figure 5-39	Water Depth (ft), Q = 48,800 cfs, Option 1**

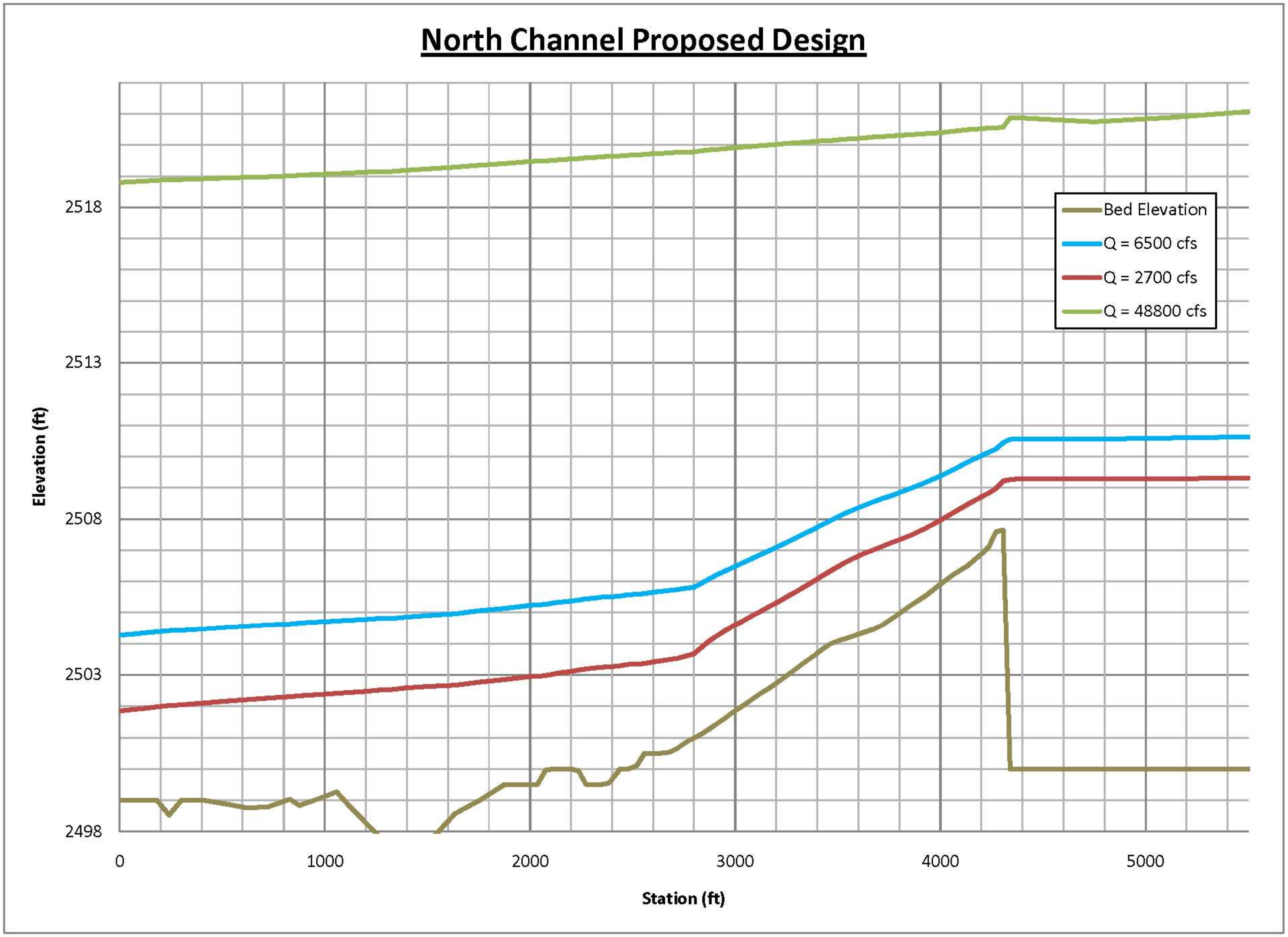


Figure 5-40 North Channel Proposed Design, Option 1

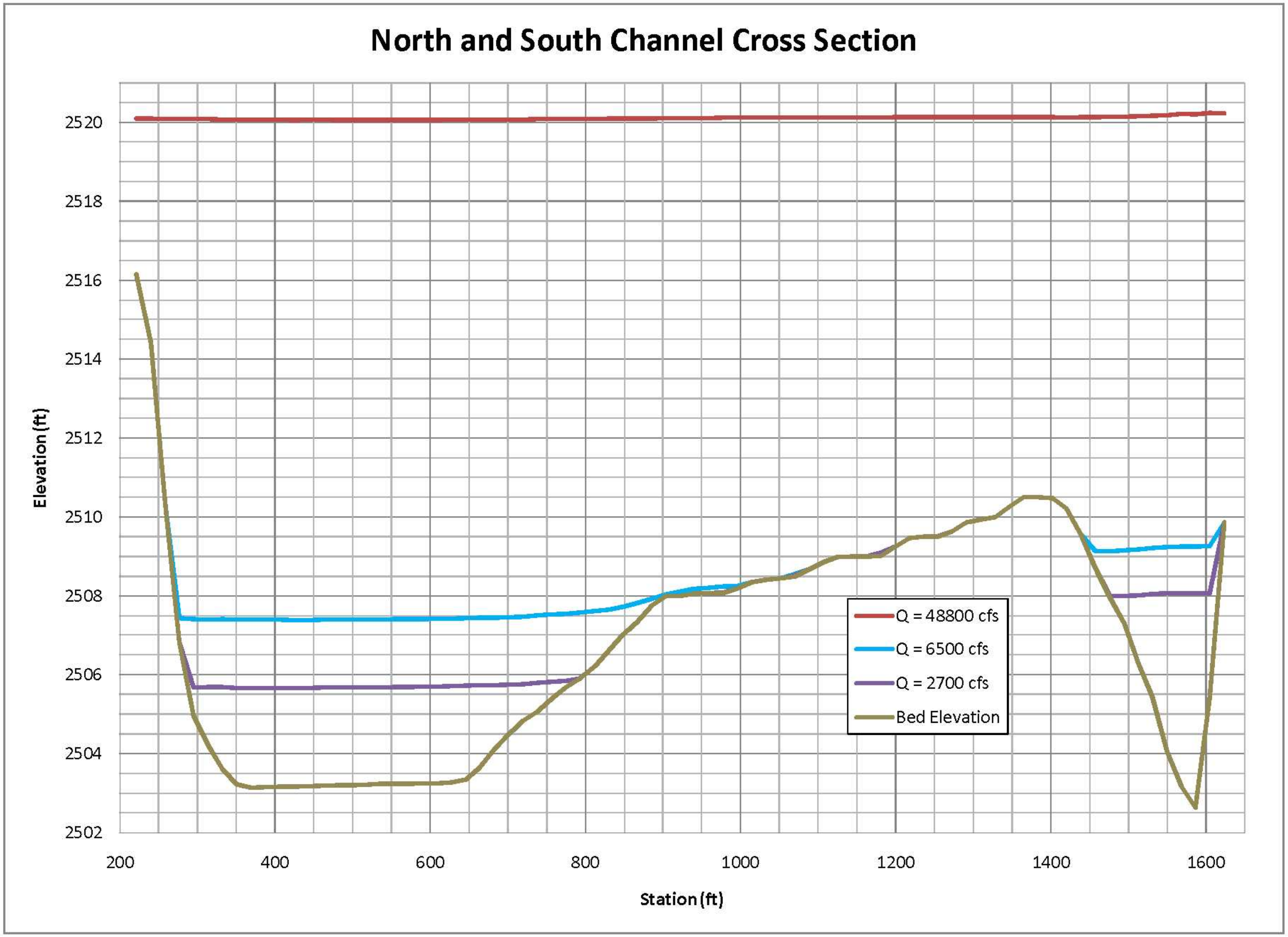


Figure 5-41 North and South Channel Cross Section, Option 1

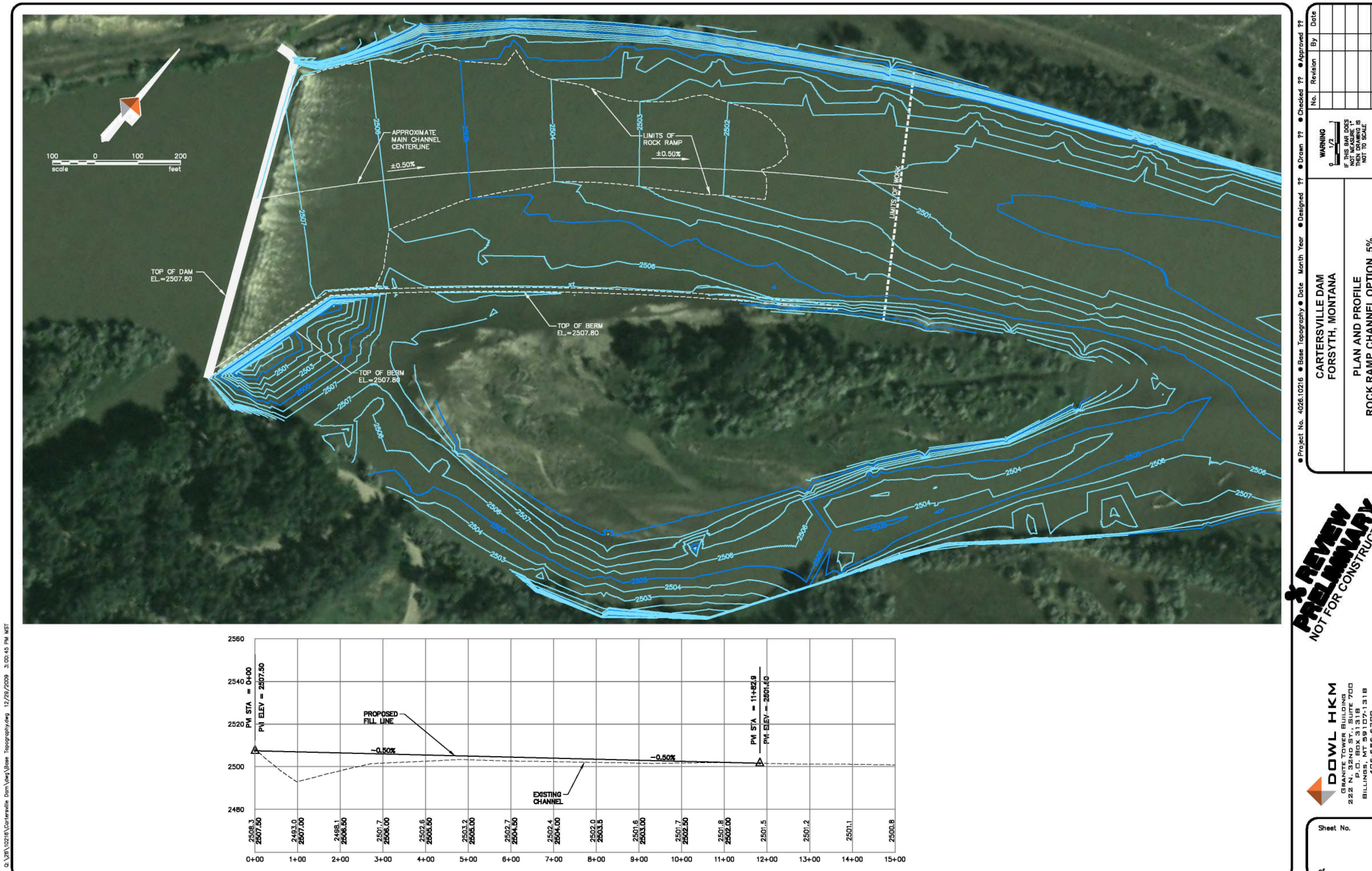


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Figure 5-42 Rock Ramp, Slope 0.5%, Option 2

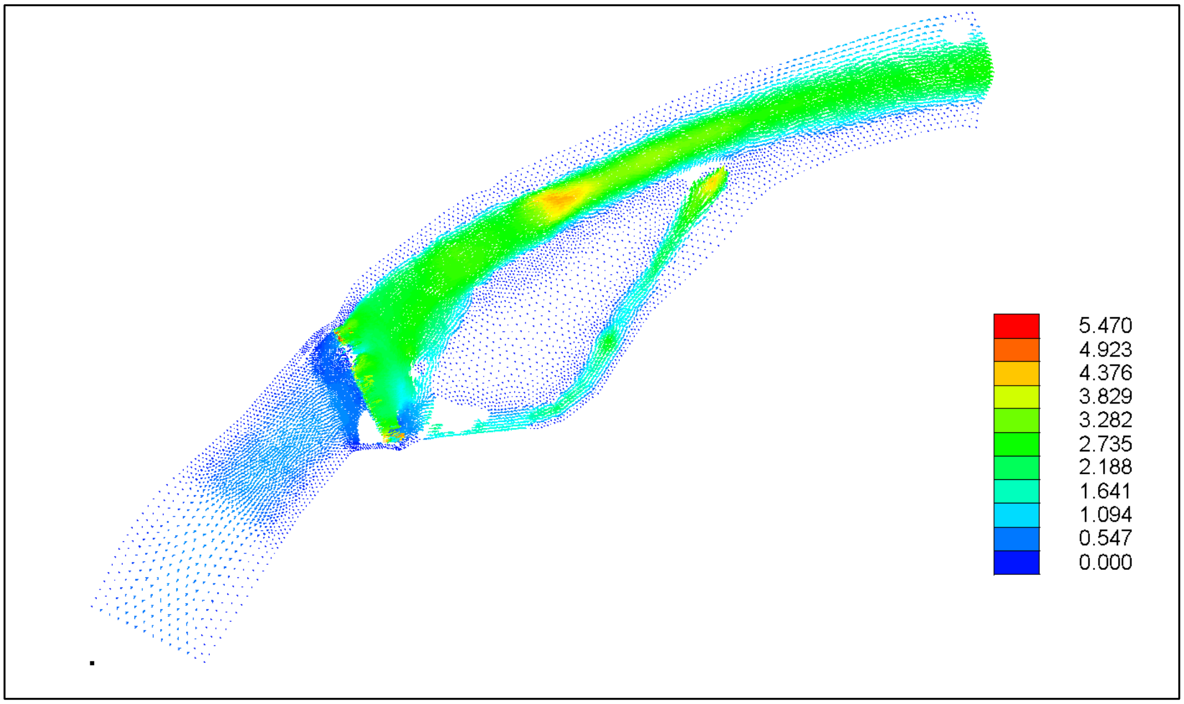

Figure 5-43 Mean Column Velocities (ft/s), Q=2700 cfs, Option 2

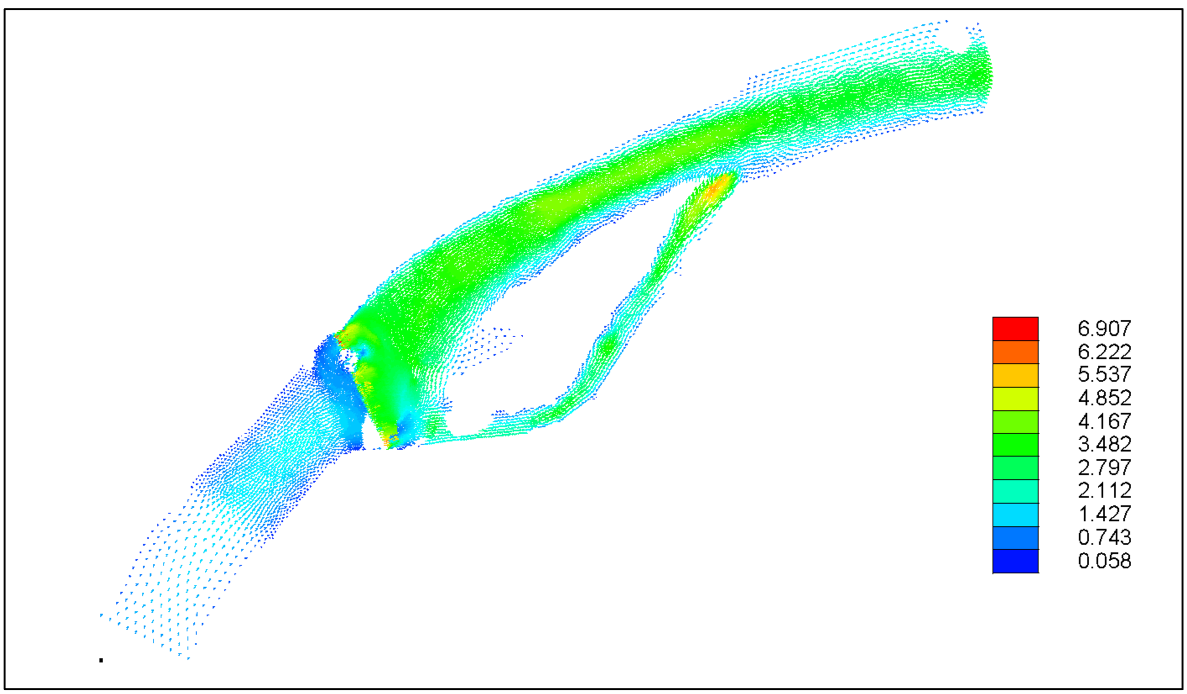

Figure 5-44 Mean Column Velocities (ft/s), Q=6500 cfs, Option 2

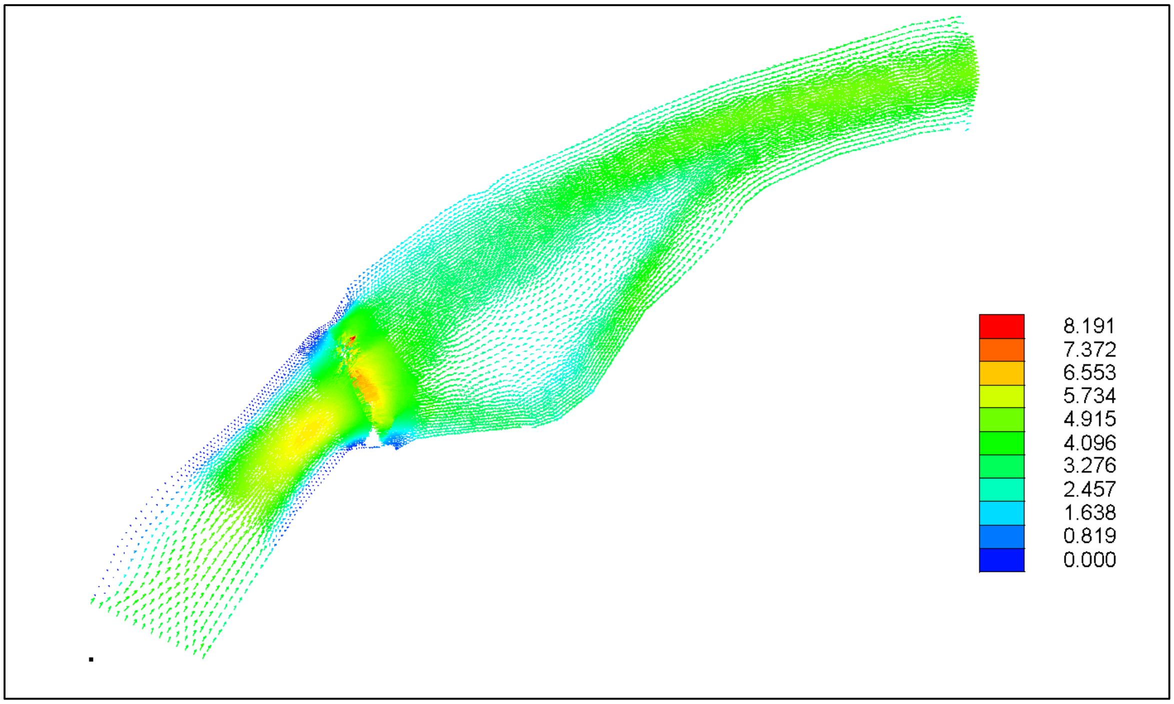

Figure 5-45 Mean Column Velocities (ft/s), Q=48,800 cfs, Option 2

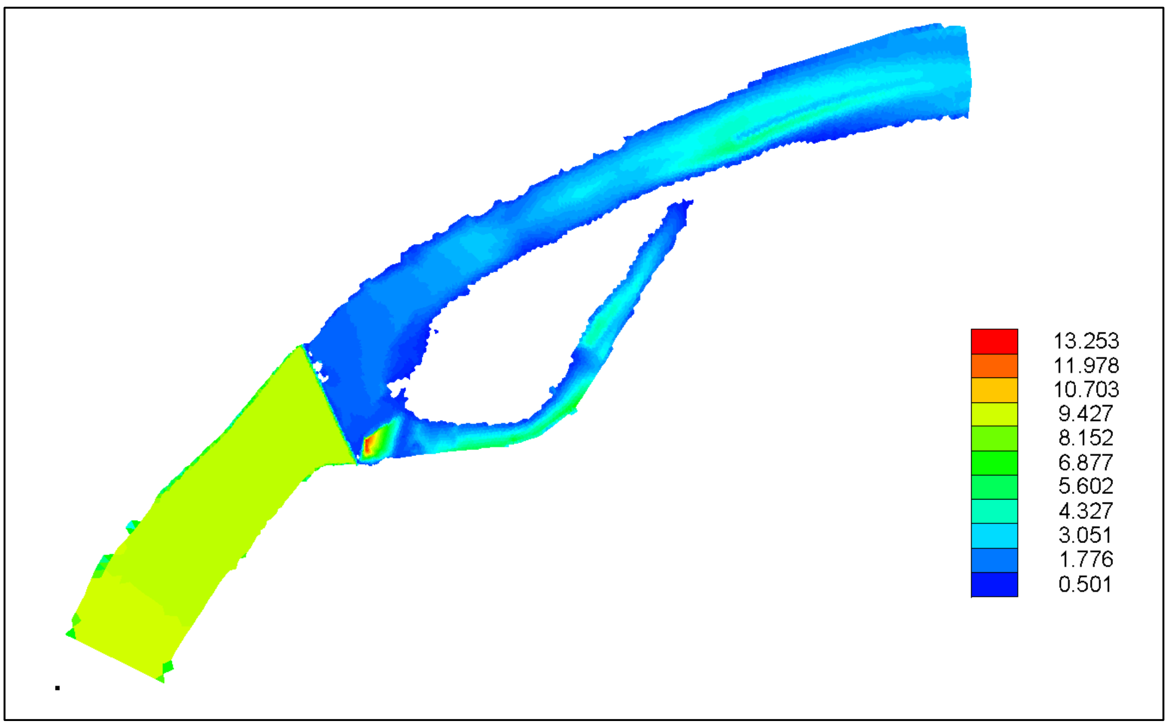

Figure 5-46 Water Depth (ft), Q=2700 cfs, Option 2

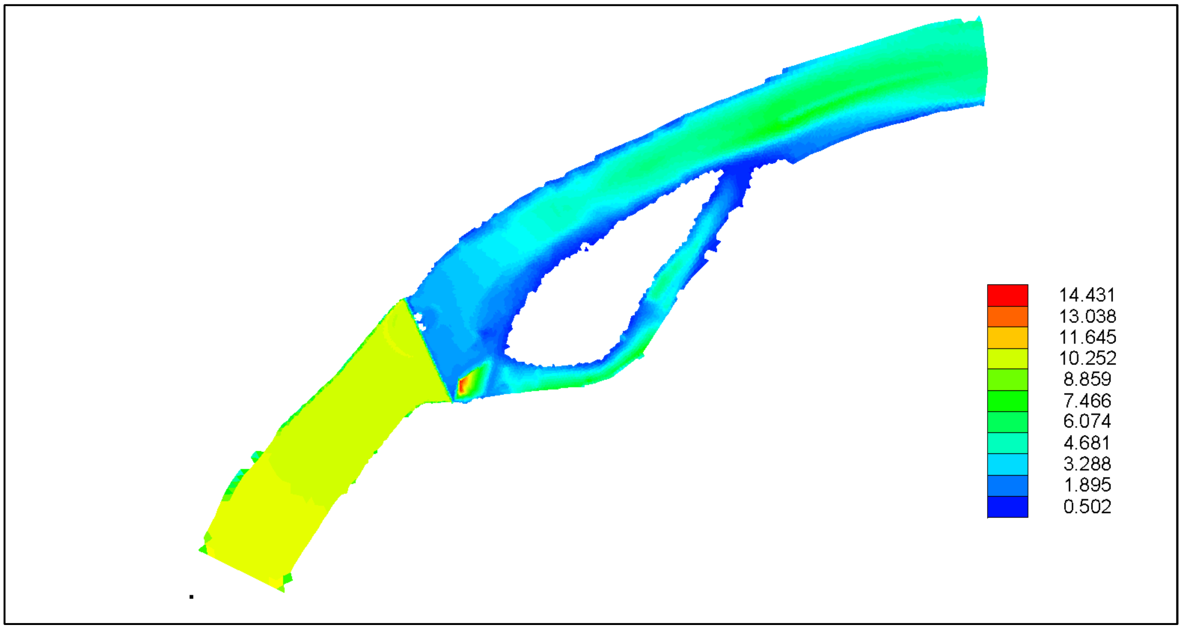

Figure 5-47 **Water Depth (ft), Q=6500 cfs, Option 2**

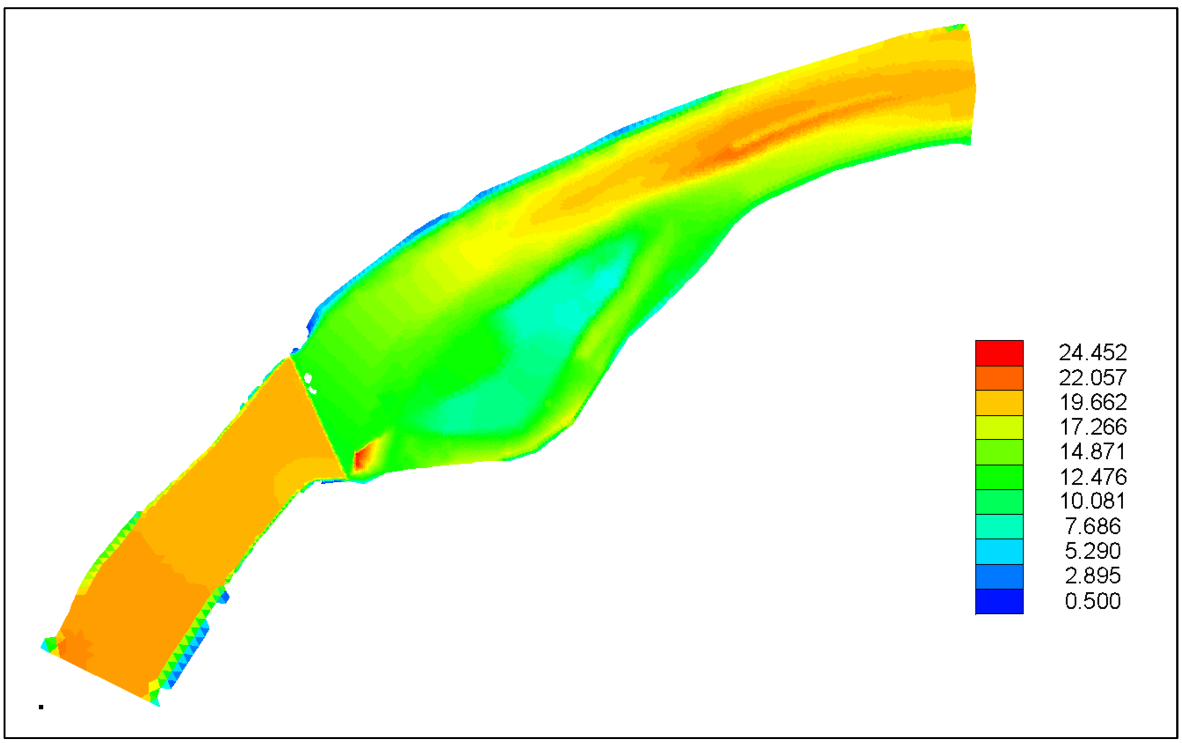

Figure 5-48 **Water Depth (ft), Q=48,800 cfs, Option 2**

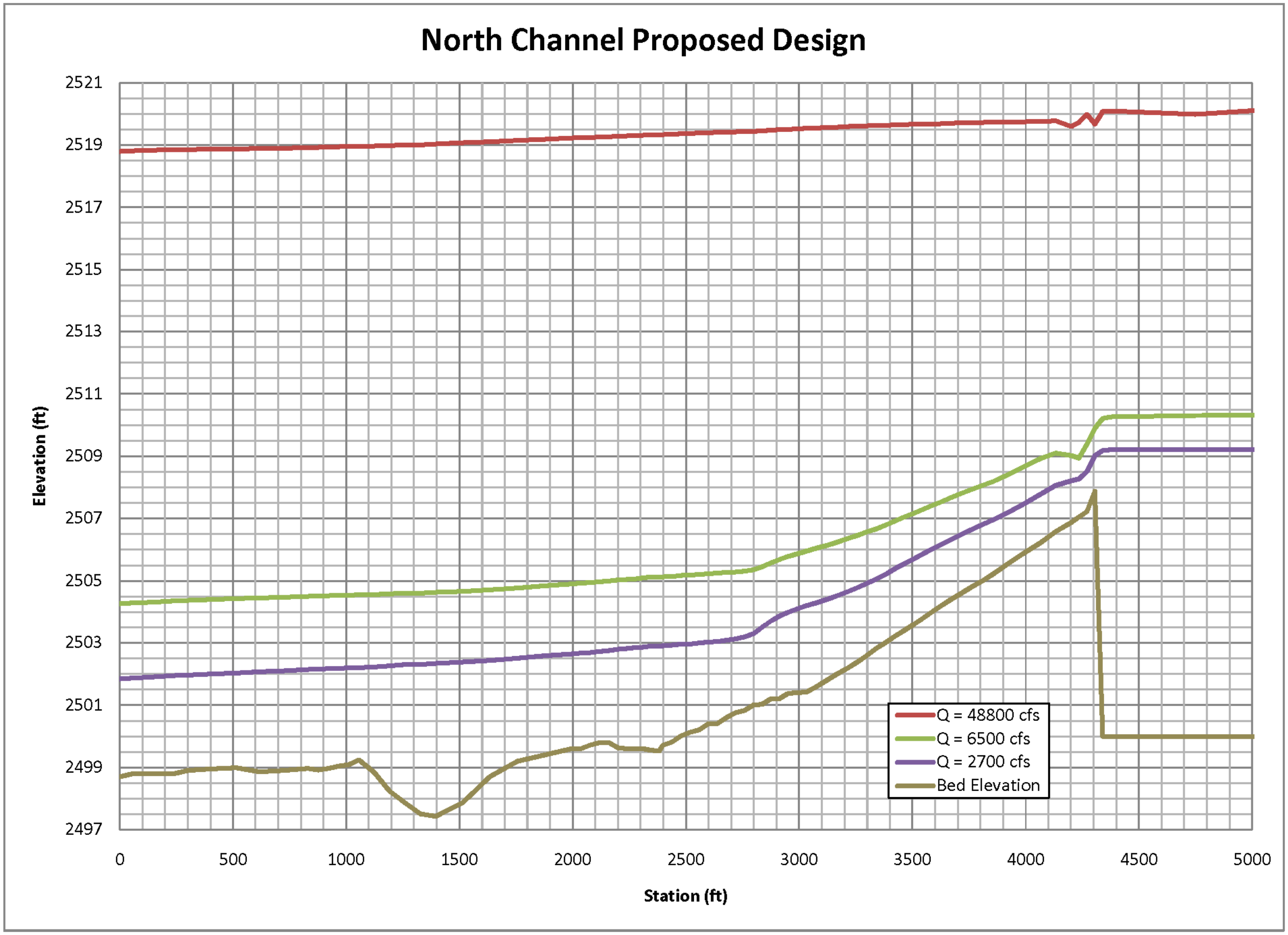

Figure 5-49 North Channel Proposed Design, Option 2

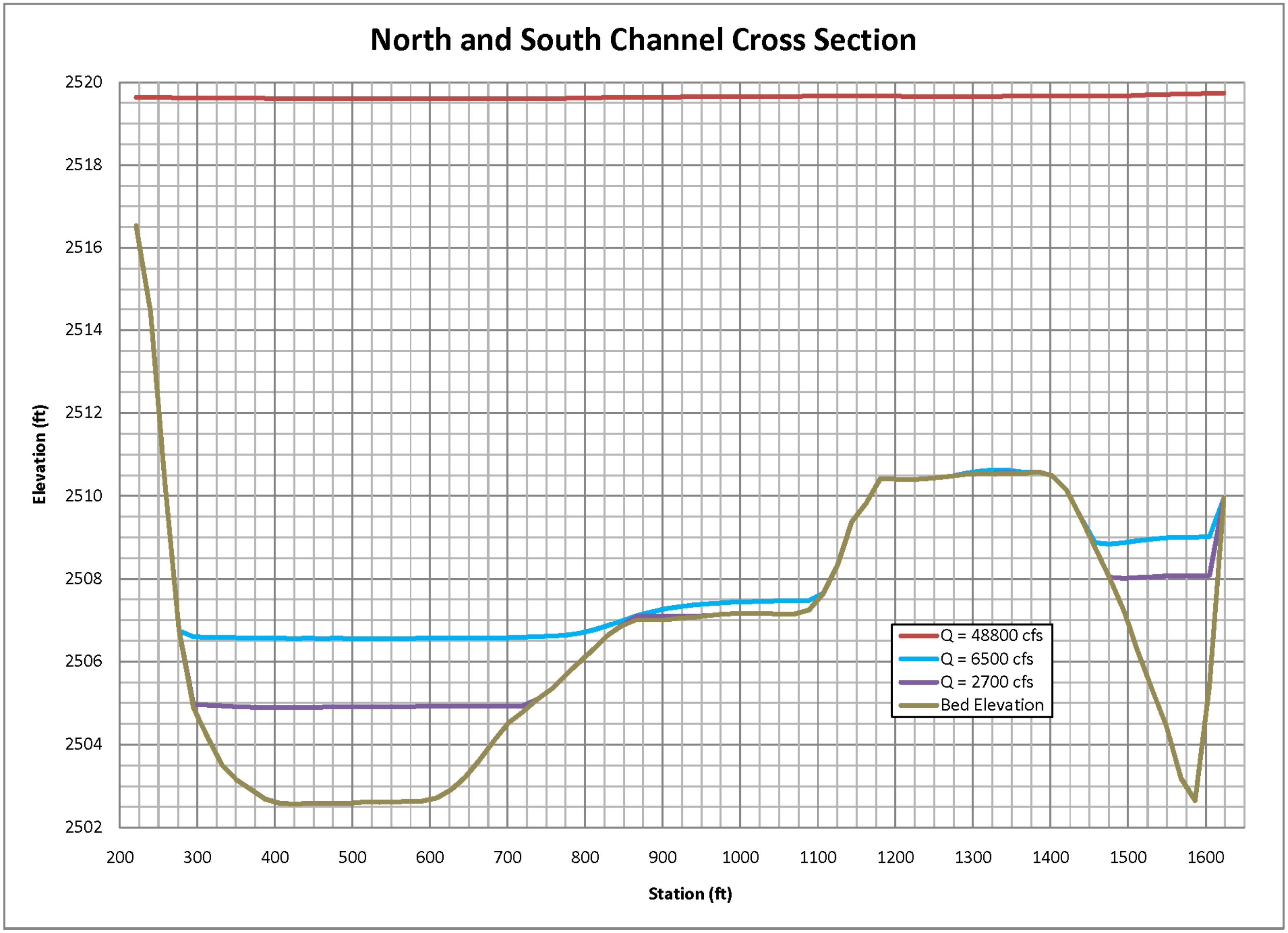

Figure 5-50 North and South Channel Cross Section, Option 2

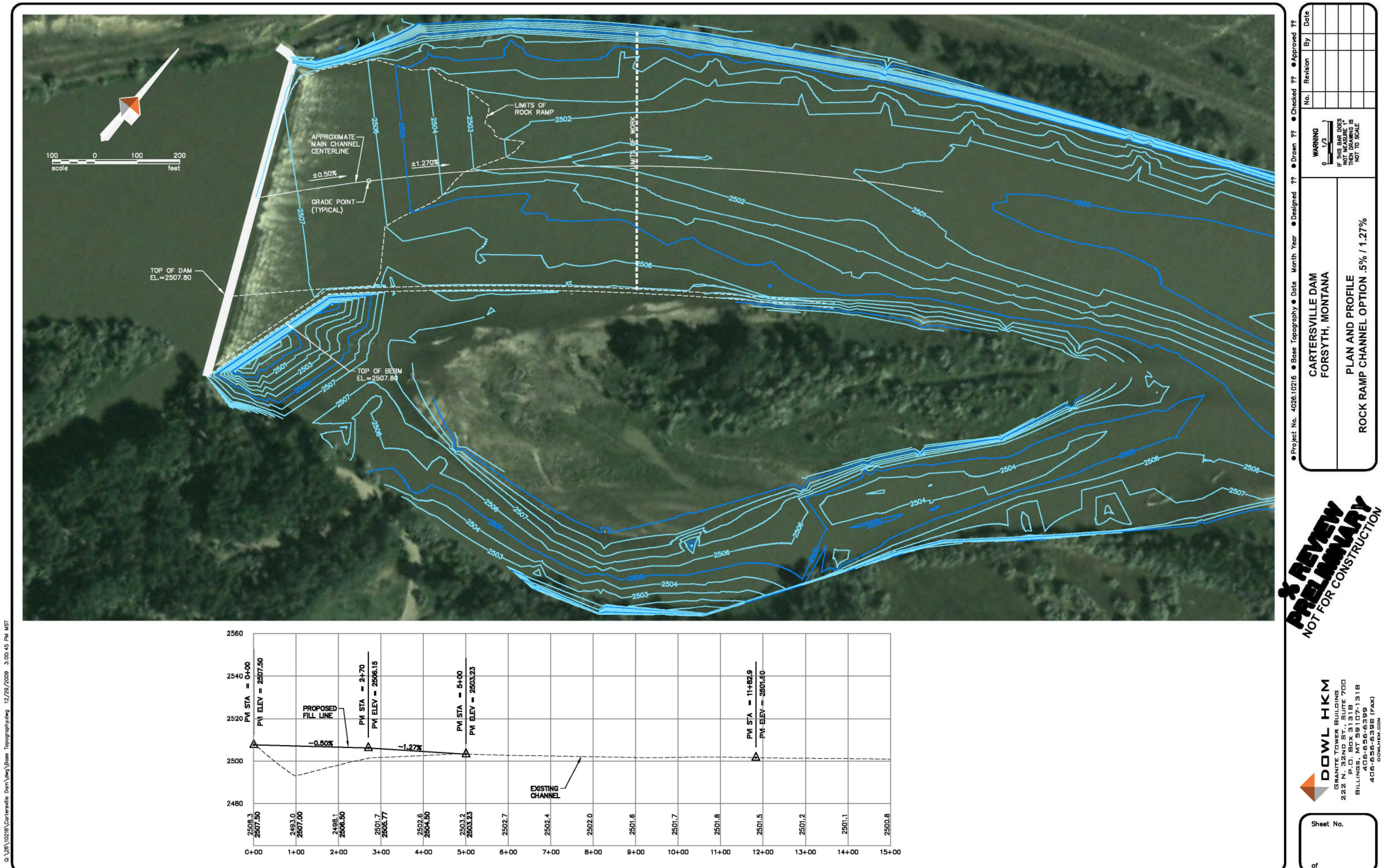

Figure 5-51 Rock Ramp, Slope 0.5% / 1.27%, Option 3

5.4.8.1.3 Potential Rock Sources and Types

Numerous suppliers were contacted to determine a source of rock for the project. Two sources were identified. The URS, Washington Division, Pipestone Quarry near Whitehall, Montana indicated the ability to deliver suitable rock in the desired quantities. The Basin Electric, Montana Limestone quarry at Warren, Montana can also supply the required rock.

5.4.8.1.3.1 Pipestone Quarry

The rock from Pipeston Quarry near Whitehall is upper Cretaceous age, porphyritic intrusive basalt/diorite (Figures 5-52 and 5-53). The rock is very dense, silicified and fractured, with no known occurrences of base or precious metal mineralization within the proposed quarry area. Refraction seismic data obtained on January 7, 1991 shows an average velocity of bedrock to be 5740 ft/sec. to a minimum depth of 50 feet (the bulk specific gravity of the bedrock is 2.852 and density of 2.4 tons per bank cubic yard). The rock would be loaded on Montana Rail Link (MRL) trains and delivered to Forsyth. Rock would then be transferred to trucks, delivered to the diversion dam, and placed in the river. A constraint is that MRL only has seven side-dump railcars which are used extensively for repairs to MRL facilities. Rock is priced at $9/ton for these quantities. Rail delivery to Forsyth is $2900/car (approximately 100 tons) or $2500/car if MRL doesn't supply the cars.

Figure 5-52 Riprap

5.4.8.1.3.2 Montana Limestone Quarry

The rock from the Montana Limestone Quarry at Warren is limestone (Figure 5-53). The rock is $20/ton FOB the Burlington Northern Santa Fe (BNSF) loading facility at Warren, Montana. BNSF will deliver the rock to Forsyth for $1369/car (approximately 100 tons). This is the least costly option.

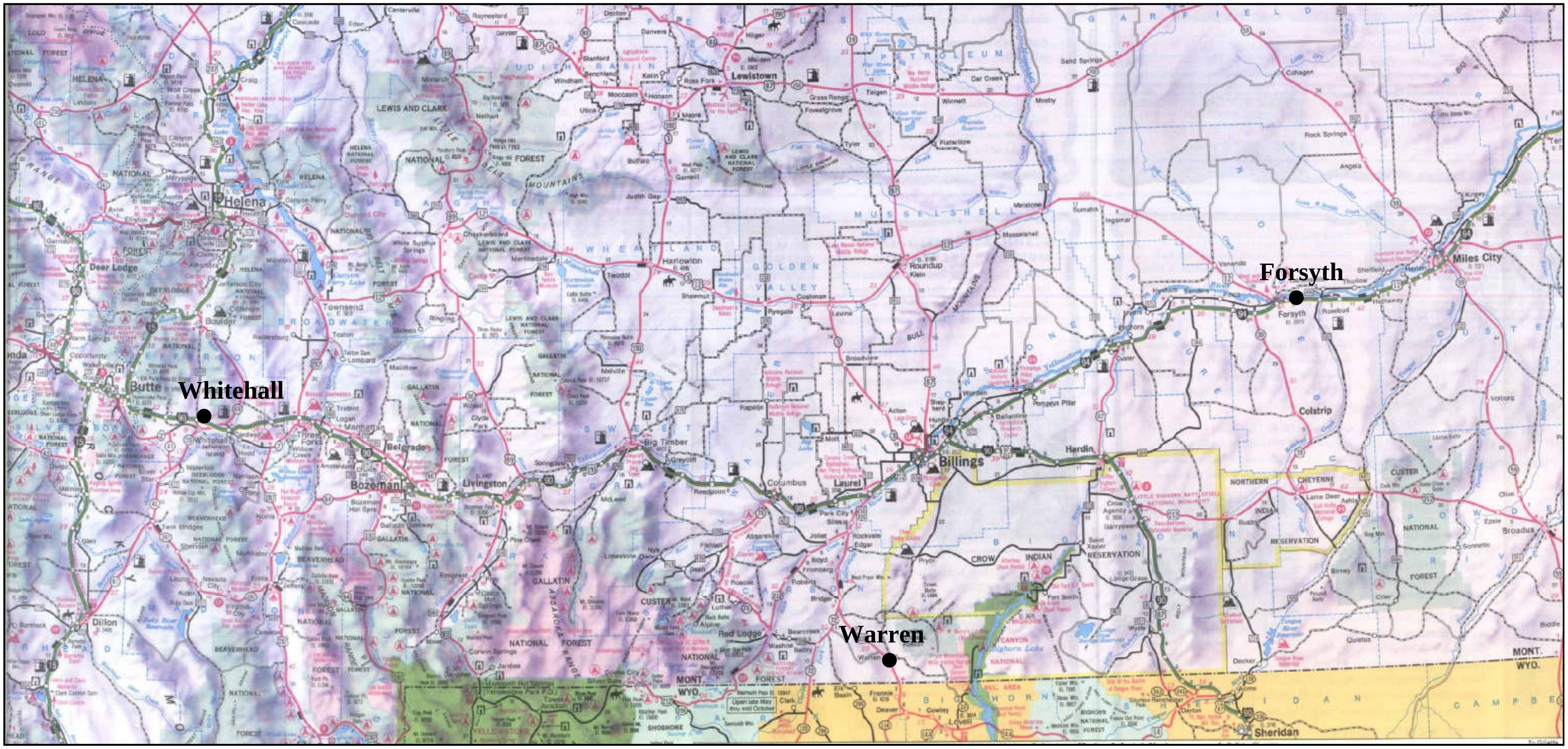

Figure 5-53 Location of Riprap Sources

Map: MDT

5.4.8.1.4 Estimated Cost

Cost estimates are presented for two rock ramp options Table 5-11:

- Option 2: Slope 0.5%
- Option 3: Slope 0.5% / 1.27%

Option 1: Slope 0.5% / 0.2% / 0.5% was eliminated from further consideration due to cost and the unnecessary inclusion of the 0.2% slope section. Option 2 with a slope of 0.5% meets all the design criteria but has an estimated cost of nearly $15 million. Option 3 with slopes of 0.5% / 1.27% meets all the design criteria except for the steeper slope at the downstream end of the structure. Option 3 results in an estimated project cost of under $10 million. Operation, maintenance and replacement (OM&R) costs are assumed to be minimal for this alternative, therefore, life cycle costs are assumed equal to project costs.

Table 5-11
Rock Ramp Estimated Costs

	Slope 0.5%				Slope 0.5% / 1.27%	
	Quantity[1/]	**Unit**	**Unit Price**	**Total**	**Quantity**	**Total**
101 Mobilization & Bonds	1	LS	5% of #103-105	$59,191	1	$36,637
102 Taxes & Insurance	1	LS	5% of #103-105	$59,191	1	$36,637
103 Riprap	226,749	Ton	$20.00[2/]	$4,534,982	140,349	$2,806,982
104 Railroad Delivery of Riprap Warren to Forsyth	226,749	Ton	$13.69[3/]	$3,104,195	104,349	$1,921,379
105 Move Riprap from Railroad & Place in Yellowstone River	139,969	CY	$30.00[4/]	$4,199,058	86,635	$2,599,058
Subtotal				$11,956,618		$7,400,694
Contingency (20%)				$2,391,324		$1,480,139
Construction Cost				**$14,347,942**		**$8,880,833**
Geotechnical (.5%)				$71,740		$44,404
Survey (.5%)				$71,740		$44,404
Mitigation (1%)				$143,479		$88,808
Engineering				$100,000		$100,000
Construction Administration				$150,000		$150,000
Project Cost				$14,884,900		$9,308,449

[1/]Assume riprap with voids 120 lbs/cf
[2/]Basin Electric / Montana Limestone
[3/]BNSF
[4/]COP Construction

5.4.8.2 Alternative 2: Inflatable Bladder

5.4.8.2.1 Introduction

The inflatable bladder alternative consists of installing an inflatable bladder across the entire Yellowstone River at the location of the existing diversion dam (Figure 5-54).

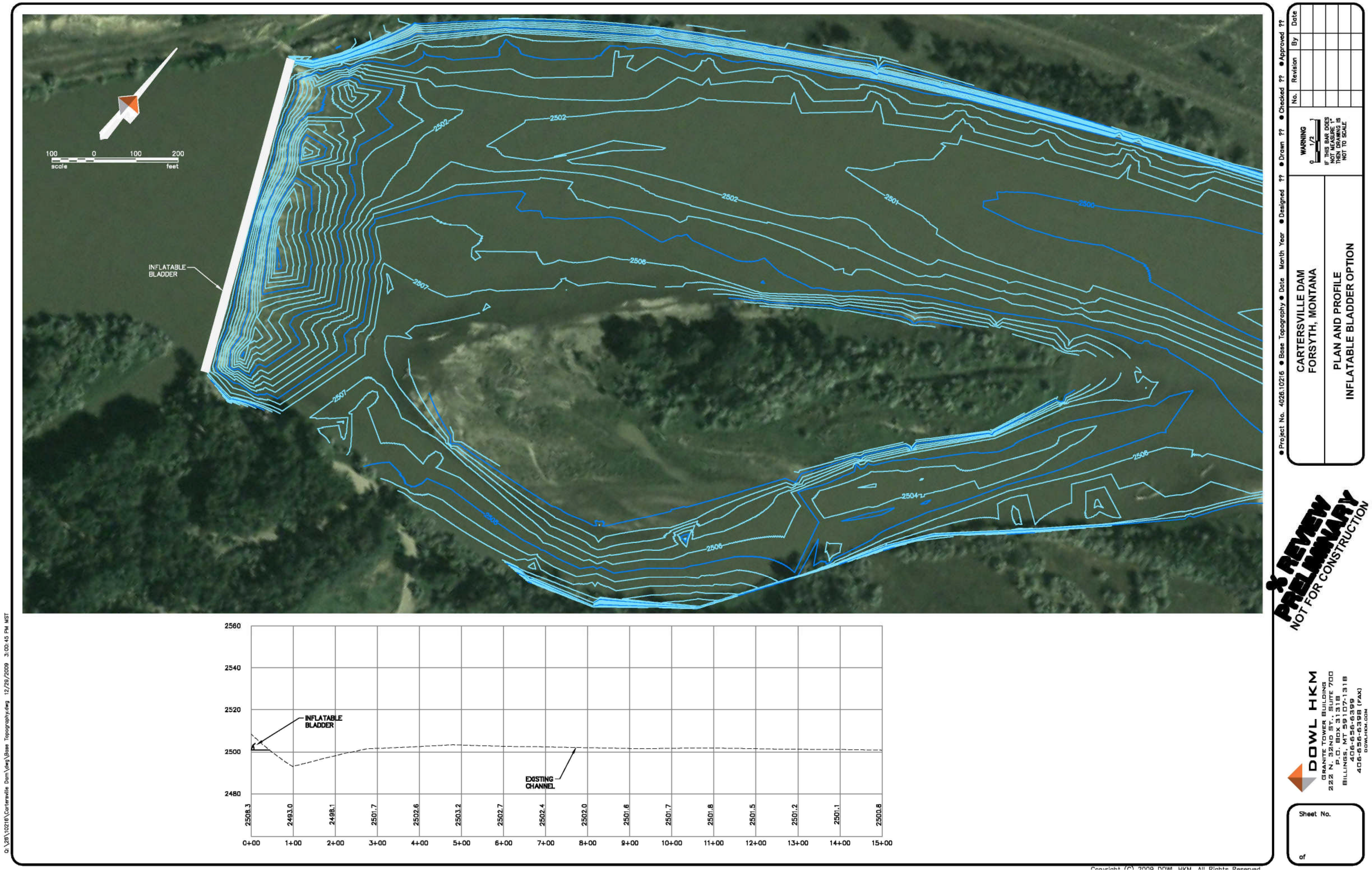

Figure 5-54 Plan and Profile of Inflatable Bladder Alternative

The bladder would be as manufactured by Obermeyer Hydro, Inc. The inflatable bladder would sit on a concrete pad with a steel plate on the upstream face to protect the bladder from damage due to ice and debris. These gates have been used extensively in areas with significant ice, such as Finland. The reinforced bladder is inflated at low pressure. The height of the bladder with steel plate would be approximately 6 feet, the estimated height of the existing dam (Figure 5-55). The bladder can be constructed in as many sections of specified width as desired. Each section can be operated independently to any desired height. This allows operation that best meets the needs of the irrigators and fish passage.

Some have voiced concern that an inflatable bladder would be vulnerable to puncture by gunshot. However, if a gunshot were to puncture the bladder the hole should self seal or the air loss could easily be made up with a small air compressor.

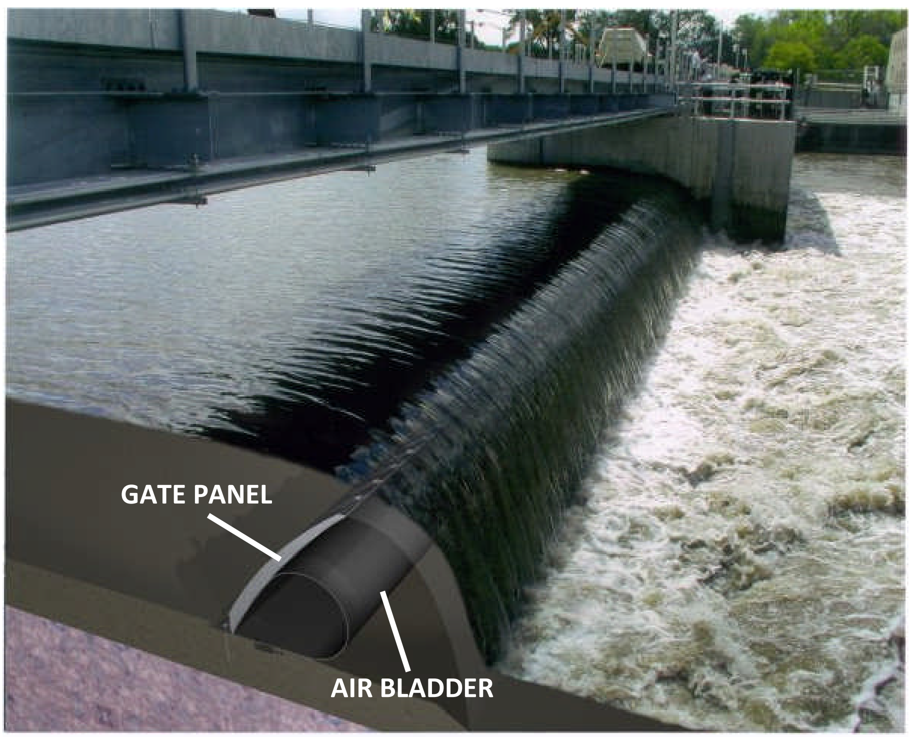

Figure 5-55 Obermeyer Gate

5.4.8.2.2 Hydraulics

With all segments of the inflatable bladder in the raised position, the dam hydraulics would approximate the existing condition. With all the segments in the lowered position the river would essentially return to a semi-natural condition, allowing unimpeded passage of fish and bedload.

5.4.8.2.3 Estimated Cost

The estimated cost for the inflatable bladder alternative is provided in Table 5-12.

Table 5-12
Inflatable Bladder Estimated Cost

	Quantity	Unit	Unit Price	Total
Mobilization & Bonds (5%)	1	LS	$281,500	$281,500
Taxes & Insurance (5%)	1	LS	$281,500	$281,500
Bladder / Steel Plate	1	LS	$2,200,000	$2,200,000
Concrete Foundation	800	ft	1/ $3,000	$2,400,000
Appurtenances	800	ft	2/ $1,000	$800,000
Demolish & Waste Existing Dam	5,000	CY	2/ $25.00	$125,000
Dewatering	1	LS	$100,000	$100,000
Subtotal				$6,188,000
Contingency (20%)				1,237,600
Construction Cost				**$7,425,600**
Geotechnical (.5%)				$37,128
Mitigation (1%)				$74,256
Engineering (6%)				$445,536
Construction Administration (10%)				$742,560
Project Cost				$8,725,080

1/ 6 feet high x 800 feet long, Obermeyer
2/ Obermeyer

The project is assumed to have a life of 50 years. The rubber components of the gate should have a life of 35 years or more according to Obermeyer. The rubber components of the gate are approximately 40 percent of the gate cost ($2,200,000 * 0.40 = $880,000). The future value of the components is also $880,000 assuming zero inflation. Using a discount rate of 4.375% and 35 years, the present value is $197,000 (personnel communication with USACE, Omaha). The cost of operating the air compressor is minimal. Adding the replacement cost to the project cost yields a life-cycle cost of $8,725,080 + $197,000= $8,922,080. The Montana DNRC sometimes has an operator on site at their hydropower dams with inflatable bladders to monitor operation. No operator is anticipated for the inflatable bladder alternative at this site.

5.4.8.3 Alternatives Considered But Rejected

Alternatives considered but rejected are the same as those discussed in section 4.0 Prior Studies.

5.5 Step 4 - Evaluation of Alternative Plans

As per the USACE guidelines, the evaluation of effects compares the conditions with-project and without-project for each alternative. Two categories of effects are evaluated: costs and outputs.

Environmental outputs (or benefits) are the desired or anticipated measurable products or results of restoration measures or plans. The evaluation consists of the following:

Forecast with-project conditions expected under each alternative.

- Compare each with-project condition to without-project conditions.
- Characterize beneficial and adverse effects by magnitude, location, timing and duration.
- Qualify plans for future consideration.

All USACE water resources development projects must be evaluated in terms of acceptability; completeness; effectiveness; and efficiency. Ecosystem restoration alternatives are also evaluated on the basis of cost effectiveness and incremental cost analyses.

5.5.1 Acceptability

Acceptability is the extent to which the alternative plans are acceptable in terms of applicable laws, regulations and public policies. The proposed alternatives are acceptable in terms of applicable laws, regulations and public policies.

5.5.2 Completeness

Completeness is the extent to which the alternative plans provide and account for all necessary investments or other actions to ensure the realization of the planning objectives, including action by other Federal and non-Federal entities. The proposed alternatives account for all necessary investments/actions necessary to ensure realization of the planning objectives.

5.5.3 Effectiveness

Effectiveness is the extent to which the alternative plans contribute to achieve the planning objectives. The proposed alternatives will make a significant contribution to restoring fish passage in the Yellowstone River system.

5.5.4 Efficiency

Efficiency is the extent to which an alternative plan is the most cost effective means of achieving the objectives. The proposed alternatives provide a cost effective means of achieving the project objectives. Refer to Section "Cost Effectiveness and Incremental Cost" for additional information.

5.5.5 Cost Effectiveness and Incremental Cost

This analysis must show through cost effectiveness that an alternative restoration plan’s output cannot be produced more cost effectively by another alternative. The term “cost effective” means that, for a given level of non-monetary output, no other plan costs less and no other plan yields more output for less money. “Incremental cost analysis” evaluates a variety of implementable alternatives and various sized alternatives to arrive at the “best” level of output within the limits of the sponsor’s capabilities.

5.5.5.1 Potential Solutions

Potential solutions include a rock ramp or an inflatable bladder.

5.5.5.2 Cost Effectiveness

Potentially implementable solutions for achieving the desired ecosystem outputs include a rock ramp and an inflatable bladder.

The project/life-cycle costs of a rock ramp with slope = 0.5% on the north channel is $14,900,000. The project/life-cycle costs of a rock ramp with slopes = 0.5%/1.27% on the north channel is $9,400,000. The associated output is that shovelnose sturgeon and other species will be able to pass the Cartersville Dam.

The estimated project cost of an inflatable bladder is $8,800,000. The estimated life-cycle cost is $9,000,000. The associated output is the same as for the rock ramp.

Both the rock ramp and the inflatable bladder are assumed to have the same output.

The inflatable bladder (Alternative 2) appears is the most cost effective solution to fish passage, but may not be a locally acceptable alternative due to the associated OM&R responsibilities and costs. The rock ramp (Alternative 1) with slopes of 0.5% and 1.27% (Option 3) is the next most cost effective if a variable slope is acceptable. Therefore, a rock ramp with a 0.5% slope is ultimately the most cost effective.

5.5.5.3 Incremental Cost

The intent is to identify the “Best Buy” plan that provides the greatest increase in output for the least increase in cost. The incremental cost of choosing between these alternatives does not yield a measurable increase in output.

5.5.5.4 Evaluation Criteria

5.5.5.4.1 Output Target

No specific output target has been established. Both the rock ramp and inflatable bladder will accomplish the objective of passing sturgeon.

5.5.5.4.2 Output Threshold

No specific output threshold has been established. Both the rock ramp and inflatable bladder will accomplish the objective of passing sturgeon.

5.5.5.4.3 Cost Affordability

USACE funding programs include Section 206 of the Water Resource Development Act (WRDA) of 1997 and Section 3110 of WRDA 2007. Section 206 provides federal funding up to $5,000,000 for eco-system restoration projects with the project cost split 65% federal and 35% non-federal. With $5,000,000 of federal contribution, the non-federal contribution would be $2,692,308, for a project cost of $7,692,308. Larger projects would require additional non-federal contributions in excess of 35%. The terms of Section 3110 of WRDA 2007 have not been established. A one-time appropriation of $30,000,000 for the Yellowstone River has been approved. The Bureau of Reclamation and WAPA may also be a source of funding. Non-federal cost-share funds include the future fisheries fund or state appropriations.

5.5.5.4.4 Unintended Consequences

The rock ramp alternative raises the water level in the north channel downstream of the diversion dam and distributes the energy loss that now is dissipated at the toe of the dam.

5.5.6 Significance of Ecosystem Outputs

The significance of ecosystem output plays an important role in the ecosystem restoration evaluation along with cost effectiveness/incremental cost analysis, as well as information about acceptability, completeness, and effectiveness. The significance of outputs from the proposed alternatives is demonstrated by Institutional, Public and Technical Recognition.

5.5.6.1 Institutional Recognition

"Institutional Recognition" means that the importance of an environmental resource is acknowledged in the law, adopted plans, a policy statement of public agencies, tribes, and private groups. The U.S. Fish and Wildlife Service; Montana Fish, Wildlife & Parks; and Yellowstone Conservation District Council have an interest in providing fish passage at Cartersville Dam for all native fish species. Moreover, once pallid sturgeon passage is provided at the downstream Intake dam, the passage barrier at Cartersville may become an issue for the endangered pallid sturgeon. (See Appendix B).

5.5.6.2 Public Recognition

"Public Recognition" requires some segment or the general public recognizes the environmental resource as important by engaging in activities that reflect an interest/concern in the resource. Organizations with a demonstrated interest in this project include the Nature Conservancy and the Rosebud/Treasure County Wildlife Association. The Cartersville Irrigation District owns the Cartersville Dam and supports the proposed rock ramp which would strengthen the dam, reducing operation and maintenance costs while providing fish passage. The residents of Forsyth support the project because it will protect and maintain an integral part of the customs and traditions of the community. (See Appendix B)

5.5.6.3 Technical Recognition

"Technical Recognition" requires the project has merit in terms of scarcity, representativeness, status and trends, connectivity, limiting habitat, and biodiversity.

5.5.6.3.1 Scarcity

The Yellowstone River is the longest undammed river in the United States and as such offers resources that are scarce.

5.5.6.3.2 Representativeness

The Yellowstone River has historically provided habitat for threatened and endangered species including the pallid sturgeon.

5.5.6.3.3 Status and Trends

Over time, a number of diversion (non-storage) dams have been constructed along the Yellowstone River. These dams, including Cartersville, have contributed to declining populations of fish species such as pallid and shovelnose sturgeon. Providing fish passage at these dams will help restore the Yellowstone River fishery.

5.5.6.3.4 Connectivity

Providing for fish passage at Cartersville will restore connectivity with the Yellowstone River. Currently, Cartersville Dam appears to block upstream movement of shovelnose sturgeon (Jaeger et al. 2009) as well as juvenile sauger (Jaeger et al. 2005). Although Helfrich et al. (1999) reported that Cartersville Dam did not create any disjunct fish populations; it is likely that upstream passage is impeded for some proportion of the 40-50 fish species present in the project area. For example, total numbers of shorthead redhorse, goldeye, Hybognathus sp. (likely western silvery minnow), emerald shiner, and river carpsucker were higher below Cartersville Dam than above it. The total number of all fish species captured was also higher below Cartersville.

5.5.6.3.5 Limiting Habitat

Removing the fish barrier at Cartersville Dam is essential for the conservation, survival, and recovery of the threatened and endangered species such as the pallid sturgeon. After fish passage is restored at the downstream Intake Dam, pallid sturgeon will need to pass Cartersville Dam.

5.5.6.3.6 Biodiversity

Removing the fish barrier at Cartersville Dam will increase the diversity of this reach of the Yellowstone River by more evenly distributing the fish species currently limited by the dam.

5.5.7 Risk and Uncertainty

The proposed rock ramp alternative with a slope of 0.5% was configured to match reference reaches in the Yellowstone River (Matthews and Wolf Rapids), scoring criteria developed by the biological review team for the similar, downstream Intake Dam, and design criteria developed specifically for this project. As such, the risk and uncertainty should be low.

A rock ramp with variable slope of 0.5%/1.27% may have a higher level of uncertainty than the constant slope of 0.5%, but could be easily modified in the future by placing more rock to provide a constant slope of 0.5%.

Replacement of the dam with an inflatable bladder would allow the bladder to be lowered during periods of high flow during periods of fish passage, while still providing water levels sufficient to supply irrigation water and water for the City of Forsyth.

5.6 Step 5 - Plan Comparison

The rock ramp alternative is acceptable to the Cartersville Irrigation District. It stabilizes their existing diversion dam while providing for fish passage and maintaining the south channel in its current configuration. A rock ramp with a constant slope of 0.5% satisfies all of the design criteria. A rock ramp with a variable slope of 0.5% and 1.27% is not supported by evaluations of the Matthews and Wolf Rapids reference reaches, but may be acceptable contingent on the ability to place additional rock in the future to provide a constant slope of 0.5% if necessary to promote fish passage.

The inflatable bladder is unlikely to be supported by the Cartersville Irrigation District due to operation, maintenance, and replacement costs. The most significant cost being replacement of the rubber bladder in approximately 35 years.

5.7 Step 6 - Selection of Ecosystem Restoration Plan

The rock ramp alternative with a constant slope of 0.5% is the preferred plan for meeting the goals/objectives of this project. While not the least cost alternative, it meets all of the goals and objectives for the project.